31October2022

Sawah Technology「アフリカ水田農法」(3-1): Overview of the Evolutional Stages of Various Sawah Platforms Based on the Ease of Water Control in Sub-Saharan African Countries, Especially in Nigeria

Toshiyuki WAKATSUKI[1)] *and Segun Yinka ADEMILUYI*[2)]

[1]*Life and Environmental Science, Shimane University, Matsue, Japan:* Mail: wakatuki@life.shimane-u.ac.jp
[2]*National Center for Agricultural Mecajnziation, Ilorin, Nigeria:* Mail: segunncam@yahoo.com

Content

1. Evolutional Stage 0: Upland rice cultivation platform with no bunding, no leveling and no human made water control. Thus green revolution technology (GRT) cannot accommodate

Photo 1–11: Various upland rice farming systems. No. 1 (Guinea) and No.6 (Sierra Leone) are typical shifting cultivation sites that destroy forests. No. 2 shows the harvesting and threshing of Fonio, which can be cultivated even in soils severely deteriorated by upland rice cultivation.

Photo 1. Guinea Highland between Labe and Dalaba, Sawah evolutionary stage 0 : Shifting cultivation of upland rice and Fonio *(Digitaria exilis)* in Guinea (August 2002)

Photo 2, Threshing of Fonio (*Digitaria iburua*<black fonio> or *Digitaria exilis* <white fonio) at Kaduna, Nigeria (September 1990). Fonio is cultivated on extremely degraded soils by erosion.

Photo 3. , Bagudo farm, approximately 4000ha, Mokwa-Bida Road, Nigeria (August 1986). Manual weeding in upland rice fields. It is very difficult to control weeds in upland fields. Evolutionary Stage 0

Photo 4. Bagudo farm (Sep. 1986). Water management is not possible in upland rice fields, which causes soil erosion, overgrown weeds and very poor supply of various nutrients, such as nitrogen, phosphorous, potasisum and silicon.

Photo No. 5. Prof. TA Okusami, Obafemi Awolowo University (OAU), Ile-Ife (September 1986)

Photo 6: IITA's Wetland Research Sites, Rogbom village area, Makeni, Sierra Leone, Dr. Palada, Huizing, and Jalloh (July11, 1986) (IITA annual reports 1988 and 1989)

Evolutionary stage 0 on uplands: Non sawah rice cultivation on all topo-sequence from ridge to valley bottom in the Robgom village areas are as shown in Photos 21-26

Photo 7. Bawku, North eastern Ghana, sorghum and rice were planted side by side. Rice is a lower topographic position. Evolutionary stage 0.

<u>The next Photo 8 shows expansion of the enlarged the farming systems on the valley bottom</u>

Photo 9. Between Kaduna and Abuja road (Oct. 1990). Lowland rice, evolutionary stage 1. Mixed cropping of Asian rice (*Oryza Sativa),* the ears of which are weighed down by a large number of grains, and Afrcan rice (*Oryza Glaberrima*), the ears of which grow upward because the ears have few branches and the number of grain is small.

Photo 10. Failed mechanized upland rice farming, SawaEvolutional stage 0. Tamale area, Ghana (1995).

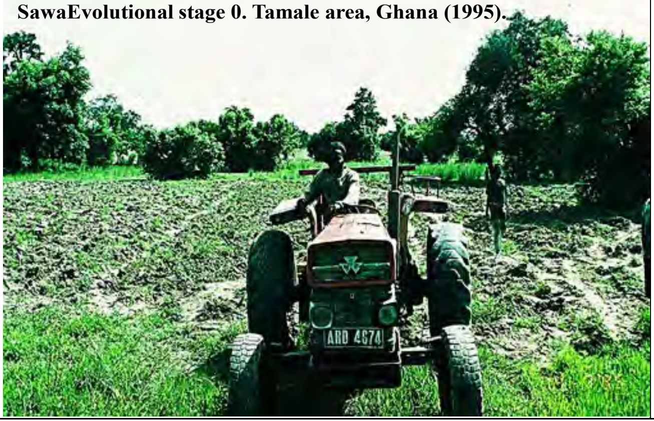


Photo 11. After rough plowing on the non-sawah evolutional stage 0. Failed mechanized upland rice farming, Tamale area, Ghana (1995)

Photo 3–5 were taken about 12 km east of Mokwa city in central Nigeria, near the branch of A1 national highway to Sokoto and the A124 route to Abuja via Bida. The junction location is **9.322N 5.147E.** These upland rice fields, about 4000 ha, were developed using large heavy machinery in the early 1980s. Within a few years, large farms have been abandoned because of the lack of control over weeds and soil erosion.
Photo 6 was taken at Rogbom village, Sierra Leone (**8.834N 12.042W**, 11July 1986, IITA Annual Report 1988 and 1989). This is evolutional stage 0 in uplands and road side. Non-sawah platform on the all toposequence from mountain ridge to valley bottom. The rice platform in valley bottom area is shown in Photos 21-26 later.
Photo 7 and 8, taken at Bawku, North eastern Ghana (**11.03N 0.293W**), show rice cultivation that is carried out from the lower part of the gently undulating toposequence to the upper part of the lowland. Thus, these photos showed an intermediate evolutionary stage from 0 to 1. Photo. 8, soil walls corresponding to the bund of the sawah plots were constructed. This is to protect the vegetables cultivated in the dry season from nomadic cows.
Photo 9 shows a mixed cultivation of Asian rice and African rice varieties.
Photos 10 and 11 show mechanized rice cultivation on an extremely gentle undulating low-lying terrain near Tamale, Ghana. This terrain surface has an intermediate character between the uplands and lowlands. This is an example of mechanized agriculture that the Ghanaian government promoted and failed in the 1970s and 90s. Agricultural land platforms co-evolve with the mechanization stage. The Sawah platform at stage 0 cannot accommodate tractor use sustainably. Thus, the productivity remains low. The platform shown in photos 10–11 show not much difference in productivity from the platform in photos 1-6, and the paddy yield is lower than 2 t/ ha. Thus, just introducing machines, such as those in photos 10–11, could not be sustained, which led to the failure of mechanized agriculture.

2. Evolutional stages 1, 2, and 3 platforms that cannot accommodate modern science and GRT: (1) Evolutional stage 1: Non-Sawah platform, that is, lowland without bunding and leveling (rainfed and irrigation system); (2) Evolutional Stage 2: Lowland under ridge cultivation (with or without bunding as well as irrigated or rainfed); and (3) Evolutional Stage 3: Lowland under micro-rudimentary Sawah platform (irrigated or rainfed).

These three evolutionary Sawah platforms for rice farming are common where the farmers' tools are mainly hoe and cutlass, that is, where plow cultivation using cattle and horses is not common.

2-1. Mali's inland delta area, Niono irrigation site, and Nigeria's Kebbi flood plain before 1990

Photos 12–15 represent the Sawah platforms, in the evolutionary stage 1 of non-Sawah rice cultivation with no irrigation. These photos were taken in 1987–1998 on the inland delta of Mali and the floodplains of the Niger River and the Rima (Sokoto) river. Most of the rice varieties are African rice (*Oryza glaberrima*). As of 2021, most have been replaced by Asian rice *(Oryza sativa*). The areas where the Sawah rice cultivation platform of stage 4-5 described in the next chapters are being developed are also increasing.

Photo 12: Gao, Mali. The inland delta of Mali is one of the areas where Africa rice (*Oryza Glaberrima)* was domesticated (January 1989). Evolutional stage 1.

Photo. 13. Rice cultivation in the inland delta/floodplain near Mopti, Mali, in October 1996 by Shinichi Takeda, in "*The Ring of Oryza in Pictures*", pp.62-63, Kahoku Shimposha, Published in 1998, Sendai, Japan, Evolutional stage 1

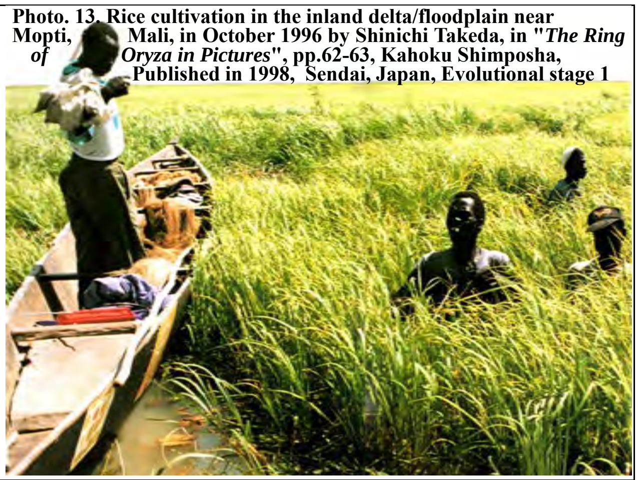


Photo 14: Mopti, Mali. Non sawah rice cultivation, the Niger River Flood plain/Inland Delta, evolutionary stage 1, August 1998

Photo 15: Africa rice (*Oryza Glaberrima*) cultivation at the Arugungu flood plain of the Rima (Sokoto) river, Nigeria, December 1987, Non sawah platform, Evolutional stage 1

Photo 16 shows the secondary irrigation canal in the center of the Niono irrigation system under the control of the Office du Niger. Photo 17 shows the irrigated rice fields around the area shown in Photo 16. This irrigation system is the largest irrigated rice cultivation system in sub-Saharan Africa, which was about 50,000 ha in 1989 and > 100,000 ha as of 2021. Photo 17 shows a Sawah evolutional stage 1. The rice was cultivated in a scattered manner, and the paddy yield was approximately 2 tons. As detailed in Sawah Technology (3-3), as of 1989, out of a total area of about 50,000 ha, a rice field of evolutional stage 4 or 5 where the transplanting method can be applied was 2700 ha (5 % of the total area) and only 500 ha in 1986. By 1998, the Sawah platform of evolutional stage 4 or 5 expanded to 48,000 ha, and the mean paddy yield exceeded 5 t/ha (Djibril and Geert 2005).

Photo No. 16. Secondary irrigation canal in Niono rice project area on 1989. Possible location 14.2N 6.002W, Mean paddy yield was about 2t/ha (Djibril and Geert, World bank, 2005). The evolutional stage of the Sawah platform was 1 on 1989 as shown in the next Photo No. 17. (direct sowing method)

Photo No. 17, Niono Irrigation site, Non Sawah, evolutional stage 1, 10Jan1989 (Estimated Location 14.2N 6.002W, 6km to Niono main road,)

2.2. Examples of inland valleys in Guinea, Ghana, and Sierra Leone

Photo 18: Kissidougou, Guinea. Non-sawah rice cultivation, Inland Valley, Evolutionary stage 1 (January 1989). Photo 19: Google earth position (9.2515N 10.128W) is the same area. In 2019, platform stage 1 was common in the Kissidougou-Gekedou area.

Photo 19: Inland valleys, 15km north of Kissidougou (9.2515N 10.128W). More than 90% of the rice platforms in inland valleys and flood plains in N'Zerekore-Gekedou-Kissidougou-Kankan-Farana-Mamou in Guinea are non-sawah platform, the evolutional stage 1.

Photo 20: Photo showing the weeding work of rice about 1 month after dibbling (spot sowing), Inland valley of the Mankran river, Ashanti, Ghana. Non sawah rice cultivation, Evolutionary stage 1. Google earth position (9.2515N 10.128W) (July 1999).

Photo No. 21: Other valleys near Rogbom valley. Degradation of Inland Valley soil by non-Sawah Paddy cultivation (January 1989).

Photo 22: Rogbom-Mankane village (8.834N 12.042W), Makeni, Sierra Leone. Evolutionary stage 1: Non sawah rice (July 1986).

Photo 23: Robgom valley in July 1986. Non-Sawah lowland rice (Stage 1). Bridge and discharge flow meters (8.8341N 12.0405W) were installed by the IITA wetland utilization research team.

Photo 24: Google Earth showing the cultivation of dry season crops, including cassava and groundnut on numerous mounds (4 April 2009). **Photo 25:** February 198 (by Wakatsuki). Google Earth on 11December 2016. **Photo 26**: Google shows rice cultivated in the wet season on micro rudimentary Sawah. **Photo 23** was taken at the bridge (○ **Photo 24** location 8.834N 12.042W), Rogbom, Makeni, Sierra Leone.

Photo 20 shows weeding about 1 month after dibbling (spot sowing) in a small inland valley, a tributary of the Mankran River, near Adugyama town, in Ashanti, Ghana. Weeding is difficult because it is a non-Sawah platform, stage 1, where water control is not possible.

Photos No. 21–26 show a small inland valley near the village of Rogbom-Mankane, 4–6 km south of Makeni, in central Sierra Leone. This site was a benchmark site for a detailed survey and on-farm research of the Rice Research Program and Resource Management Program of the International Institute of Tropical Agriculture (IITA) from 1981 to 1989 (IITA 1988, 1989). This research was conducted under the theme of Wetland Utilization Research Project in West Africa, and it was a joint study with the International Institute for Land Reclamation and Improvement (ILRI), STIBOLA (Soil Survey Institute, Wageningen), and KIT (Royal Tropical Institute, Amsterdam) in the Netherlands. In addition, a detailed basic agro-ecological survey on the benchmark sites in Sierra Leone and Nigeria and a West African–wide general basic survey was also conducted (Windmeijer and Andriesse 1993). Other benchmark sites for this project were Matam-Romangoro, Makeni, Sierra Leone, Gara, Anfani, and Gadza valleys, Bida, Nigeria. One of the authors (T.W.) promoted this project in 1986–1988 as a researcher at the IITA.

Photo 21 was taken in mid-January 1989 during the dry season, immediately after harvesting rice. Two images in Photo 21 show the relatively large downstream inland valleys near Rogbom Valley. Rice growth was poor because of the lack of a water control platform, that is, the Sawah evolutional stage 1. Because water cannot be managed without proper bunding systems, clay components of surface soils are washed away by running water (**Photo 23** shows the Rogbom Valley in the relatively upstream area. Photo 23 was taken in July 1986 during the rainy season). Thus, the soil was very sandy. The annual rainfall is 3000 mm in the Makeni area; hence, if there are no drainage systems, reinforced bunds, or dams for proper control of soil erosion and flood, such as the Sawah platform, soil erosion and degradation are inevitable on the long run, as shown in Photo 21.

Photo 22 shows rice cultivation at the beginning of the rainy season in the inland valley near the village of Rogbom-Mankaneno. Rice is randomly transplanted to the moist soil of the valley bottom, evolutional stage 1. **Photo 25** shows numerous mounds created at the valley bottom immediately after rice harvest. Cassava, peanuts, and sweet potatoes were cultivated on these mounds. After harvesting, the mounds were flattened for rice cultivation during the rainy season. **Photo 24** (Google Earth in April 2009) shows numerous mounds all over the inland valleys at the end of the dry season. As the rainy season progresses, rice and weed grow, as shown by the yellow circle area in **Photo 26**. Weeding and bunding create a (3–5 m) × (3–5 m) sized micro-rudimentary Sawah platform at the evolutional stage 3. Photo 22 shows the evolutional stage 1, which occurs immediately after transplanting rice. Micro-rudimentary Sawah of evolutional stage 3 can be seen in the latter half of the rainy season, as shown in Photo 26. This micro-rudimentary Sawah, which are common at the biggest official irrigation schemes in Kano, Nigeria, will be discussed in detail in the next section on the traditional rice cultivation of the Nupe people, Bida in Nigeria. The red circle in Photo 24 shows the location of the bridge in Photo 23. A discharge meter on the bridge was installed in 1986–1987 using the rice cultivation program of IITA (IITA 1988, 1989).

2-3. Examples of Inland Valleys and Flood plains in Bida, Niger state, Nigeria

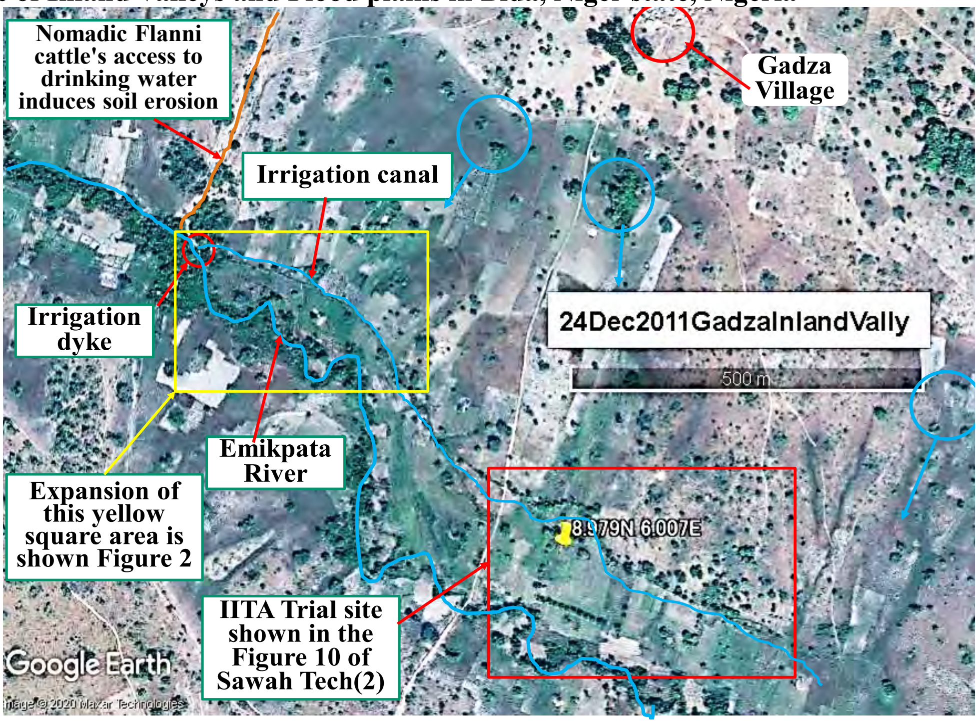


Figure 1. One of the Benchmark Inland Valley site of IITA, Gadza, the Emikpta River, Bida, Niger State

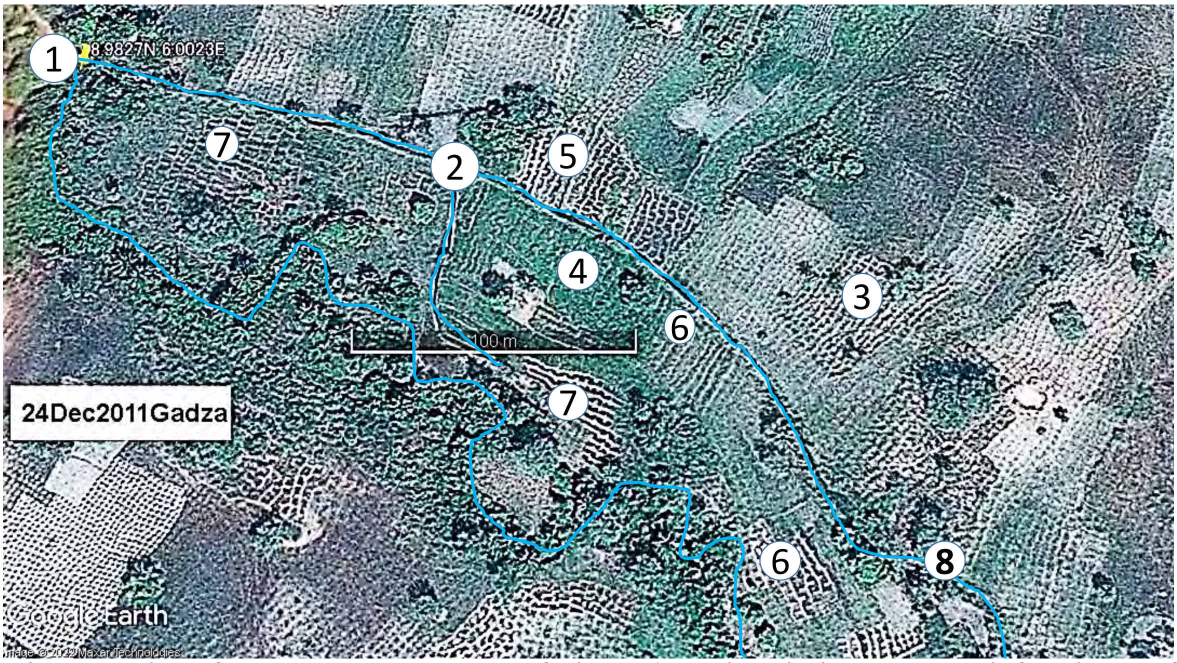


Figure 2. Expansion of the yellow square area of Figure 1. Various irrigated and rainfed rice platforms, that is., ① Irrigation weir by Bida Agric Development project managed by Gadza farmers, ② Irrigation canal ③ Spring and ④ Weir irrigated micro-rudimentary Sawah system, ⑤ Spring and ⑥ Dyke irrigated ridge/micro-Sawah, and ⑦ irrigated ridge rice planting

Figure 1 shows the benchmark site at which various on-farm trials and basic surveys were conducted between 1986 and 1995 (IITA 1988, 89, 90; Carsky and Masajo 1992; Hirose and Wakatsuki 2003). The three blue circles indicate the springs distributed along the fringe line between the upland and valley bottoms. Distribution of Nupe sandstone mainly in the Bida area, of approximately 3 million ha, in Niger State, Nigeria, which has a thick aquifer. This became a natural underground dam, and the Nupe people have been irrigating rice and other plants, such as tomatoes, eggplants, pepper, and okra, during the dry season for more than 100 years before independence in 1960 (Fu et al 2010).

As shown in Figure 2, the inland valley of the Emikpata River near Gadza village shows almost all types (evolutional stages 1–3) of traditional lowland rice cultivation platforms found in sub-Saharan Africa when hoes of various sizes were the only farming tools that can be used with or without an irrigation system and cattle cultivation and power tillers were not available. Photos No.27–29 were taken at ① location; No.30 was at ②, No33–35 and No.38 were taken at ③ –⑦ areas.

Photo 27: Concrete weir constructed by Niger State Agricultural Development with the supported World bank. The renovation and management of the weir were done by Gadza farmers. Blue arrow line shows irrigation canal. This photo was take at ① in Figure 2.

Photo 28: Concrete weir being repaired by farmer's group (April 1995). Photo was taken at ① location in Figure 2.

Photo 29: This photo was taken just at the neck position of the weir (Photo 27 and 28), showing a large herd of nomadic Fulani cattle crossing the irrigation canal before and after drinking water, which destroyed the neck position of the canal.

Photo 30: Farmers repair irrigation canals destroyed by the passage of large numbers of nomadic cattle and surface runoff from upland. The photograph was taken at location ⑧ in Figure 2.

Photo 31: Farmers' interceptor canal; the intake point is shown by brown arrow ① in the Photo 33; irrigation for rudimentary micro Sawah system, ShabaMalik, Bida, Nigeria, August 2009

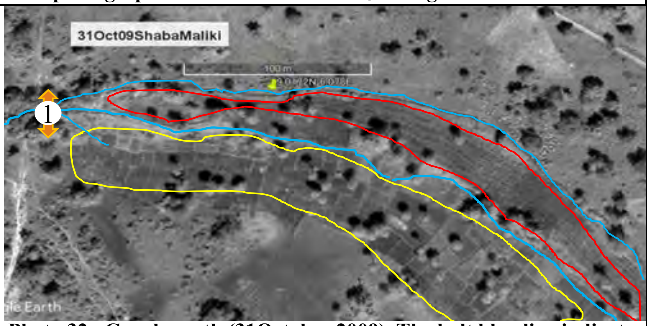
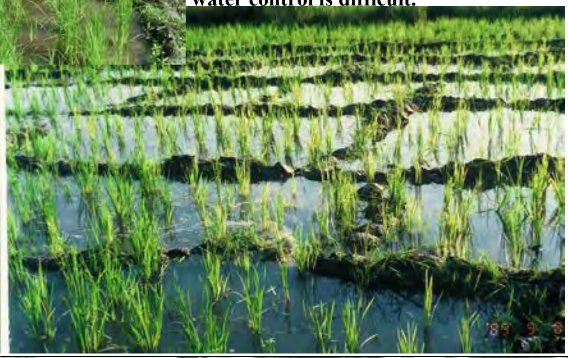


Photo 32: Google earth (31October 2009). The bolt blue line indicates the river, and thin blue line indicates the irrigation canal. The brown arrow ① indicates the dike. Rice fields surrounded by red lines indicate micro rudimentary sawah. The yellow-lined area shows semi-sawah plots developed by farmers (Abe et al , 2012, 2015, Takahashi 2010).The location of the yellow pin I 9.0172N 6.078E, which is almost the same as the position of the three people (Dr. Alarima in the center) standing on the bund of the interceptor irrigation canal in Photo 31.

Photo 33 (location is shown as ③ in Figure 2): Spring water irrigated micro-rudimentary Sawah system platform. No integration of Fulbe grazing with Nupe rice farming. Animal traction and/or small machinery is necessary for standard sawah platform based rice cultivation.

Phot 34: Location around ③ and ⑤ area in Figure 2. Weir Irrigated lowland micro-rudimentary Sawah platform. Farmers are busy weeding. Because bunds are fragile and have no leveling, water control is difficult.



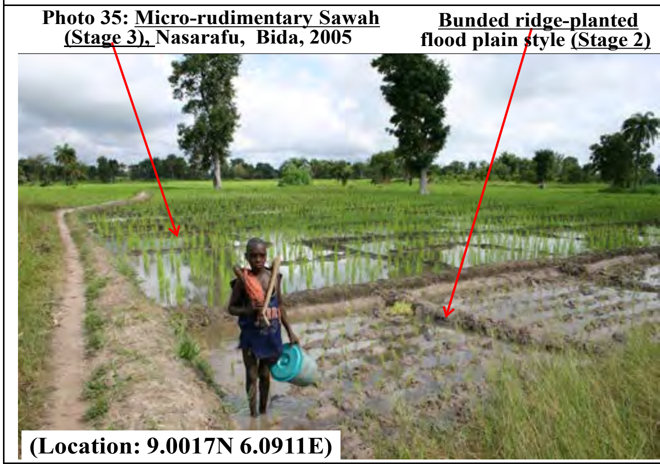


Photo 36: *Togo Gi Naafena* in Nupe (Ishida et al 1998). Rudimentary Sawah with bunds that are not closed. A Nupe style rice cultivation platform that extends running water from the long main bund to supply water to rice as widely as possible under no field leveling. Blue line indicates the irrigation canal

Photo 37: Irrigated rudimentary Sawah system for partial water control (September 2005). The brown line shows the demarcation of land owners and the yellow lines show open bunds.

Photo 38: The ridge making. The location is shown as ⑦ in Figure 2. One of the advantages of this method is that even thick and tall weedy lands can be prepared easily for seeding with just a hoe. The ridge method is suitable for direct sowing as it avoids excess flood water and reducing conditions.

Photo 39: Irrigated ridge rice cultivation as shown ⑦ in Figure 2. The disadvantages of this system include difficult water control and, thus difficult weed control during rice cultivation

Photo 40: Harvesting of ridged rice. Common in floodplain. In Nupé rice cultivation, the ridges are flattened because the soil on the ridges is stripped off with a small hoe to weed.

Photo 41: Flood plain of the Gbako river, near Nasarafu village, Bida (September 2009). Flood-damaged rice planted on ridge. Irrigation water for both weirs and springs is available on this land.

Photo 42: Ridge rice planting, the Nasia River basin, Nyankpala-Tamale area, Northern Ghana (September 1995). Evolutional stage 2

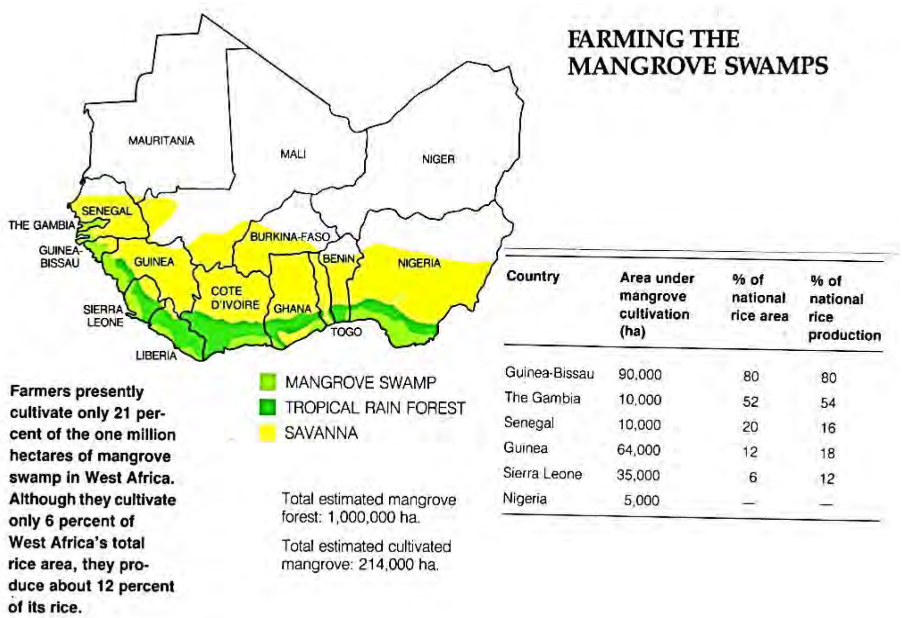
Photo 43: Construction of weir by Nupe farmers, using woods, grass, soils, and sand bags in Bida area, which is effective mainly in the dry season. In the rainy season, the weir is damaged, but the system can work as interceptor canal irrigation. This is one of the biggest one constructed on the Musa river, East of Bida. The blue arrow indicates irrigation canal. This photo was taken in February 1987

Photo 44: Nupe's traditional intake weirs and irrigation canals in the Pategi / Lafiagi region on the opposite bank of Bida, across the Niger River. This area is also used by Nupe people for rice cultivation and fishing. Weir using woods, grass, soils, and sand bags

The ridge Sawah platform is evolutional stage 2, in which rice is planted on the ridges, similar the other upland crops, such as maize, sorghum, and millet. The micro-rudimentary Sawah platform, evolutional stage 3, which is surrounded by poor bunds, can be seen in the same area. These two platforms are used to divert and retain water flowing on the surface of lowlands as widely as possible (micro-rudimentary Sawah) and to promote the germination of directly sown rice seeds without transplanting even under flooded conditions (ridge Sawah platform). Unlike the platforms of evolutional stage ≥ 4, the level of water control was much poorer than that of perennial platforms. These three platforms are created by hoe for weeding and water dispersion. Bunds can easily be destroyed if farmers walk on bunds. It often coexists with the non-Sawah rice platform (Evolutional Stage 1) where seeds are scattered and spotted (row sowing is rare) or transplanted after being cultivated by a hoe. As rice cultivation progresses, the platform stage is raised from 1 to 3 to improve water management. The platforms of stages 2 and 3 will be returned to stage 1 after harvesting to prepare for the next planting. These three platforms are not perennial and will convert to each other within 1–2 years. These three platforms are described in the same chapter. They can also be found in rice farms under rainy conditions and in official irrigation project sites.

2-4. Mangrove swamp ecology in Guinea Bissau and Sierra Leone

Figure 3 shows the mangrove swamp distribution including annual mangrove rice cultivated areas in West African countries (WARDA 1988). As shown in Figure 1, the distributions of coastal lowlands are not so wide in SSA. However, these ecologies are very important for some countries. The total area of mangrove rice area cultivated in 1988 was Guinea Bissau 90,000 ha, Guinea 64,000ha, Sierra Leone 35,000ha, Gambia 10,000ha, Senegal 10,000ha, and Nigeria 5,000ha. Total estimated mangrove forest is 1 million ha (WARDA 1988). Based on Landsat and satellite imagery and secondary data, Adefurin and Zwart (2017) gave the detailed estimated rice production data in 2013 for Guinea Bissau 102,000ha, Guinea 54,400ha, Sierra Leone 31,000ha, Gambia 9000ha, and Senegal 1000ha respectively.



Country	Area under mangrove cultivation (ha)	% of national rice area	% of national rice production
Guinea-Bissau	90,000	80	80
The Gambia	10,000	52	54
Senegal	10,000	20	16
Guinea	64,000	12	18
Sierra Leone	35,000	6	12
Nigeria	5,000	—	—

Figure 3: Map showing the mangrove swamp distribution in West African countries. Cited from "A Decade of Mangrove Swamp Rice Research" by AfricaRice (WARDA:West Africa Rice Development Association), 1988

Figure 4 and Photo 45 show the tidal irrigation system of the coastal wetlands and river system along the Gulf of Guinea, north of the capital city of Sierra Leone. The upper left yellow pin shows GPS position of 9.05N and 13.024 W. The lower right yellow circle shows Rokupr Mangrove Rice Research station of West Africa Rice Development Association (WARDA), currently Africa Rice Center. As shown in Figure 4 and Photo 45, fresh river water, indicated by a blue color, flows down from the upper land side, and tidal seawater (shown in red) flows upward into the river water bottom from the direction of the sea side, which pushes up the freshwater on the river surface. Rice farmers intercept this surface fresh water into their rice farms through their canals, as shown in Photo 45 A and Photo 46. Photo 46 is cited from the report by Campredon (2020), International Union for Conserve of Nature (IUCN), “Where rice, mangroves and dikes connect in Guinea-Bissau.

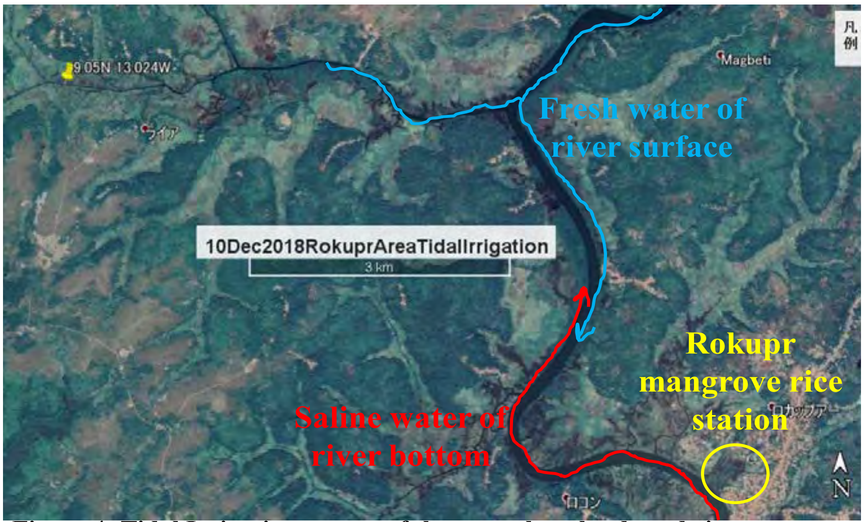


Figure 4: Tidal Irrigation system of the coastal wetlands and river system along the Gulf of Guinea. The upper left yellow pin shows GPS position (9.05N 13.024W) and the lower right yellow circle shows Rokupr Mangrove Rice Research station of WARDA, Sierra Leone.

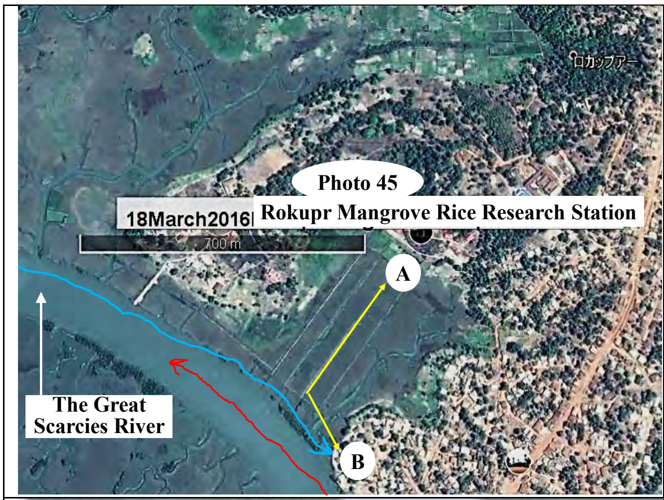


Photo 45A was taken at the A position of Photo 45 at experimental field of Rokupr rice research station (23July 1986). Currently Rokupr Agricultural Research Center (RARC), Sierra Leone, in 2022.

Photo 45B shows mangrove trees growing on bank of the Great Scarcies River, which was taken at the B position of Photo 45 (23 July 1986)

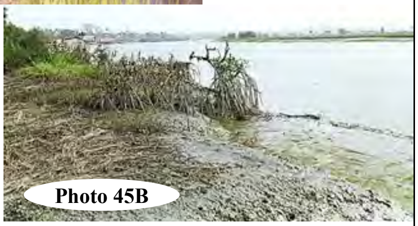


Photo 46. This is cited from the report by IUCN(2020), International Union for Conserve of Nature, “Where rice, mangroves and dikes connect in Guniea-Bisau”, https://www.iucn.org/news/forests/202002/where-rice-mangroves-and-dikes-connect-guinea-bissau

Photo 47A and 47B show mangrove rice fields and tools. Although the land is flat, micro-topography has a strong influence on rice cultivation, that is, (1) the red circled microdepression and irrigation /drainage areas are susceptible to saline water, (2) small micro-uplands are susceptible to acid sulfate soils, and (3) overgrowth of weeds.

Both photos are cited from “A Decade of Mangrove Swamp Rice Research” by AfricaRice (WARDA: West Africa Rice Development Association), 1988

Photos 47a and 47b show mangrove rice fields and tools. Although the land is flat, micro-topography has a strong influence on rice cultivation. (1) The red circled micro-depressions and irrigation/drainage areas are susceptible to saline water. (2) On the topographical surfaces with a relative height of only a few tens of centimeters, the oxidation of iron sulfide (pyrite) makes the soil strongly acidic (acid sulfate soils), which hinders the growth of rice. (3) Although the soil is relatively fertile, weeds that are resistant to the salt in the soil increase, making it difficult to control weeds, as shown in Photo 47b. (4) Because of the very flat and diverse micro-topography, it is very difficult to control water, especially drainage. Combating these four problems requires an advanced water management system (Sawah platform), making it difficult for traditional tidal irrigation systems to achieve paddy yields above 4 t/ha.

Figure 5: Google earth image of the south of Kamsar town, Guinea Bissau, at GPS position of 10.6455N and 14.494W. The location is close to the area in Photo 38. Figure 5 and Photo 46 show the overview of the tidal irrigated rice field platform. Figure 5A and 5B are enlargement of the red rectangle area in the center of Figure 5

Figure 6A: An enlargement of the red rectangle area of Figure 5 (at the end of the rainy season).

Figure 6B: Google Earth image in Jan 2022 in the dry season on the same site as Figure 5A.

Figure 5, 6A and 6B show Google earth image of the south of Kamsar town, Guinea Bissau, with GPS position of **10.6455N and 14.494W**. The location is close to the area in Photo 46. Figure 5 and Photo 46 show the overview of the tidal irrigated rice field platform. Figure 6A shows the expanded Google earth image at the GPS position (10.6455N and 14.494W) in Figure 5. Figure 6A image shows rice growing season (30th, November 2019) and Figure 6B shows dry season (January 2022). The tidal irrigated rice fields of both Figure 6A and 6B look like large Sawah plots, but they are not leveled. It is further subdivided into numerous elongated compartments, of which has rice planted numerous ridged. Although irrigation is carried out by the ebb and flow of the tide, it is practically difficult to manage water on farmland. Therefore, in this state, the so-called modern agricultural technology cannot be applied, and the Green Revolution cannot be achieved (a mixture of Sawah platform evolutional levels 1–3).

2-5. Traditional tidal irrigation and rainfed rice cultivation system in Casamance, southern Senegal

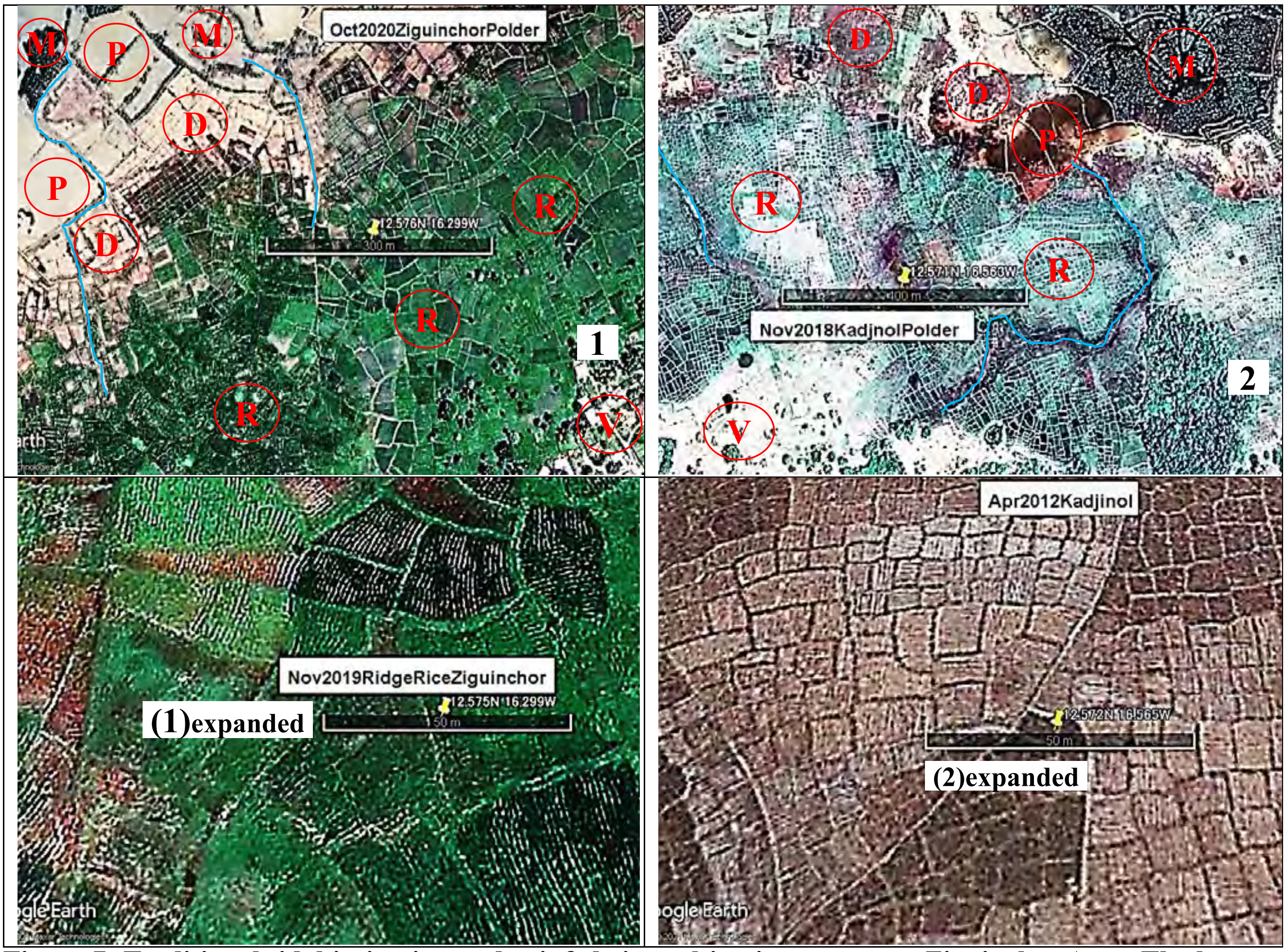


Figure 7: Traditional tidal irrigation and rainfed rice cultivation system at Ziguinchor Area. The bottom two are images magnified 6×6 times around the yellow arrows in the upper (1) and (2), respectively.

Figure 7 (1) shows a polder area developed on the mangrove forest of the floodplain of the Casamance River, which is adjacent to the northwest of Ziguinchor city. Figure 7 (2) is also a polder adjacent the northeastern part of Kadjinol city, which is 30 km west of Ziguinchor. The Casamance River flows into the Atlantic Ocean approximately 20 km west of Kadjinol town. Figure 8 shows a schematic diagram of the traditional tidal-irrigated/rainfed rice cultivation system in the Dilola polder (Van der Zaag, 2006). The exact location of the Diora reclaimed land is not clear, but two sites, (1) and (2), are believed to be in the same area along the Casamance River. The schematic drawing of Figure 8 and Google images of (1) and (2) in Figure 7 can be compared. The places shown by (V) in Figure 7 indicate the villages or towns, which are located on a sandbar or plateau. Soils of the (V) areas are sandy, and the relative height is more than 2–4m higher than the mangrove forest floor (M) and the river surface. Clayey soils under mangrove forests are acidic sulfate soils that become strongly acidic with drying and oxidation. Figures 7 and 8 shows both traditional tidal irrigation and rainfed rice cultivation systems that can control soil acidification, saltwater from the sea, and them use of rainwater and freshwater from upstream rivers.

The reclaimed land begins at the bottom of the high sandy plateau, where the village is located and extends towards the mangrove area of the Casamance River. In the Google Earth image of (1) in Figure 7, the upper left shows the Casamans river side, and the lower right shows the Ziguinchar town side. The altitude at the edge of Ziguinchar city is 3-4 m in relative height; the agricultural land directly below it is 2 m, and it gradually drops to the mangrove zone at an altitude of 0 m of the Casamance River. In example (2), the relative height of the edge of the city is 7 m, the relative height of the adjacent agricultural land is 5 m, and the relative height of the mangrove belt is 3 m. As shown in Figure 8, the height difference between the water surface of the mangrove zone at low tide and high tide was approximately 1.5 m. The zones marked with (P) in (1) and (2) of Figure 7 show ponds created between the undeveloped mangrove belt and rice farming zone. These ponds are surrounded by dikes (bunds) with a relative height of 0.5–2m and have water gates. They are used as fish ponds and for salt production, but they are also useful for controlling tidal irrigation in rice fields, oxidation and acidification of rice soils, and the salinity of both surface water and ground water, as shown in Figure 8.

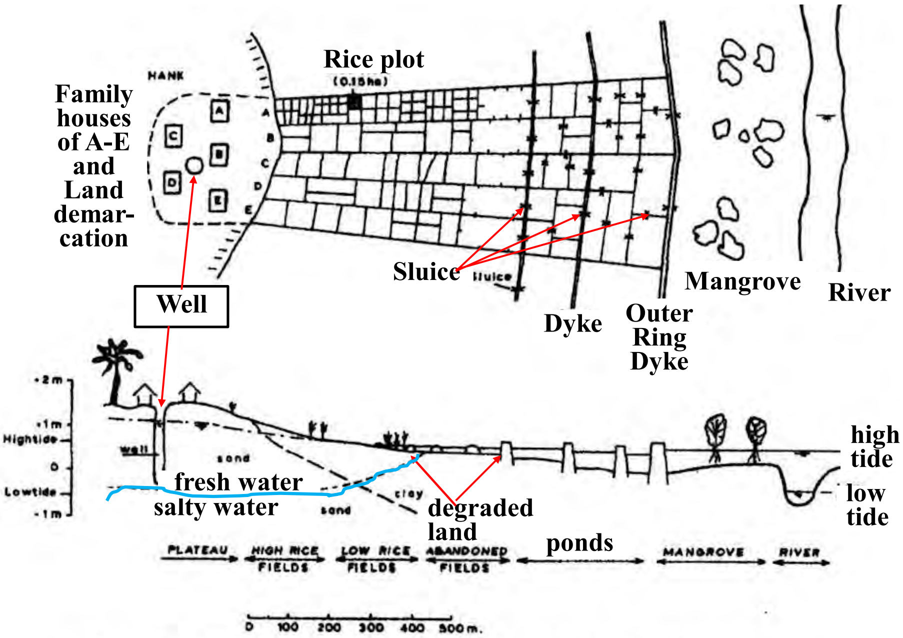


Figure 8: Schematic diagram of Dilola rice polder near (1) (Ziguinchor) and (2) (Kadjinol) areas in Figure 7 (Van der Zaag, 2006).

When fallowing rice fields during the dry season, farmers keep the water level at its maximum by allowing river water to flow into the pond at high tide. This keeps the water table of the rice field high, which prevents the soil from drying out, thus preventing acidification. At the same time, salt flows into the soil, and because of the early rain, the salt can be washed away by the ridges and grooves between the ridges created in the rice fields. This salt water was drained from the pond at low tide. The ridges of the rice field were cultivated after the elution of salt on the soil surface. When the rice field is flooded with rainwater, the rice seedlings are transplanted. It is important to store fresh water from rainfall in rice fields. In addition, since the Casamance area has ample rainfall of 1250–1500 mm, freshwater flows down from the upper reaches of the Casamane River during the rainy season. At high tide, seawater flows into the bottom part of the river; thus, freshwater on the surface of the river water can be taken into ponds and rice fields. By keeping the groundwater level in the rice fields high in this way, freshwater can be contained on the surface of Sawah (paddy) plots. As shown in Figure 8, there is a shallow freshwater surface in the rice plots, below which is salty groundwater. There is a freshwater layer on the surface of rice fields. Below that fresh water layer is a layer of salt water. Fresh water has a lighter density than saltwater. Thus, freshwater cannot penetrate deeper underground. Well water necessary for village life can also be kept fresh.

2-6. Official irrigation sites of Kadawa and Kura in the Kano River Basin, Nigeria

Figure 9 shows Google earth image of the GPS position **11.8077N and 8.4745E** of the central area of Kura area of the Kano irrigation project site. As shown in Figures 7A, 7B, and 7C as well as Figure 9 in Sawah Technology 「アフリカ水田農法」(2) "Background on Co-Evolution of Genetic and Ecological Technology" in separate paper, the Kano irrigation scheme is one of the biggest official irrigated rice area, 15000 ha approximately, in Nigeria. However almost all the rice cultivation platforms are micro-rudimentary Sawah platform of evolutionary stage 3; thus, GRT cannot work properly and yield cannot be > 3 t/ha. An example can be found in the Google earth image below.

Figure 9. Google earth image of Kura site of Kano Irrigation Scheme at the 11.8077N 8.4745E position on 20, August 2016, showing that all the irrigated platforms are micro-rudimentary Sawah plots of size 20–30 m^2 (The central marker is 200m long)

2-7. Edozhigi irrigation site, Niger state, Nigeria

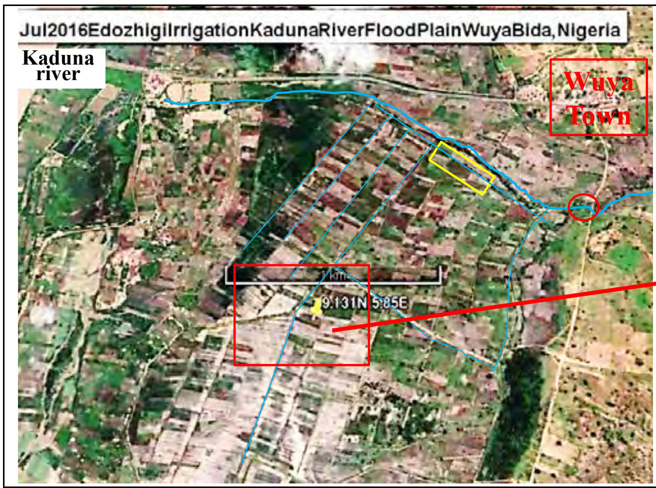


Figure 10A: Overview of the Edozhigi irrigation Scheme on the Kaduna river flood plain (2000 ha approximately).

Figure 10B: Expansion of the area surrounded by a rectangular red line (location of 9.131N 5.850E) of Figure 10A.

Figure 10A shows the Edozhigi irrigation Scheme on the Kaduna river flood plain (2000 ha). Irrigation water is introduced at the point shown in red circle from the Kupanko river, which is indicated in thick blue line. Thin blue lines show irrigation canals installed at every 100 m. Although all canal lines are not shown, the straight lane markings every 100 m indicate their position and are also access roads for farmers.

Figure 10B is the expansion of the location of 9.131N 5.850E of Figure 10A. Thick Blue lines shows secondary irrigation canals and access road. Thin blue lines show tertiary irrigation canals. Thick green areas show sugar cane. The other countless elongated sections are the ridges for rice cultivation.

Photo 48 (taken in August 2005) and Photo 49 ① (taken September 2014) as well as Photo ② (taken December 2014) show irrigated ridge rice planting platform. Photo 49 ③ (taken in October 2014) shows sugar cane. These photographs were taken near the area surrounded by a rectangle indicated by the yellow line in Figure 10A. These are irrigated ridge rice cultivation platform, evolutionary stage 2 with no leveling and no bunded Sawah platform at official Edozigi irrigation scheme, Bida, central Nigeria.

Photo 48: Irrigated ridge rice planting platform (August 2005)

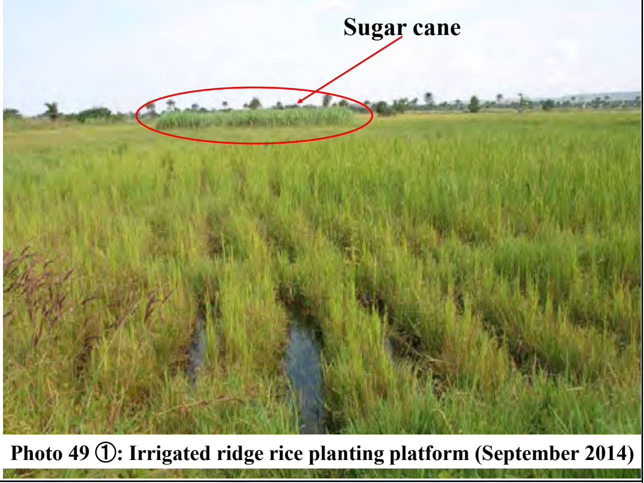


Photo 49 ①: Irrigated ridge rice planting platform (September 2014)

Photo 49 ②: Ridge rice after harvest (December 2014)

Photo 49 ③: Pump irrigated sugar cane (October 2014)

2-8. Official irrigation sites of Wurono and Goronyo, Sokoto State, Nigeria

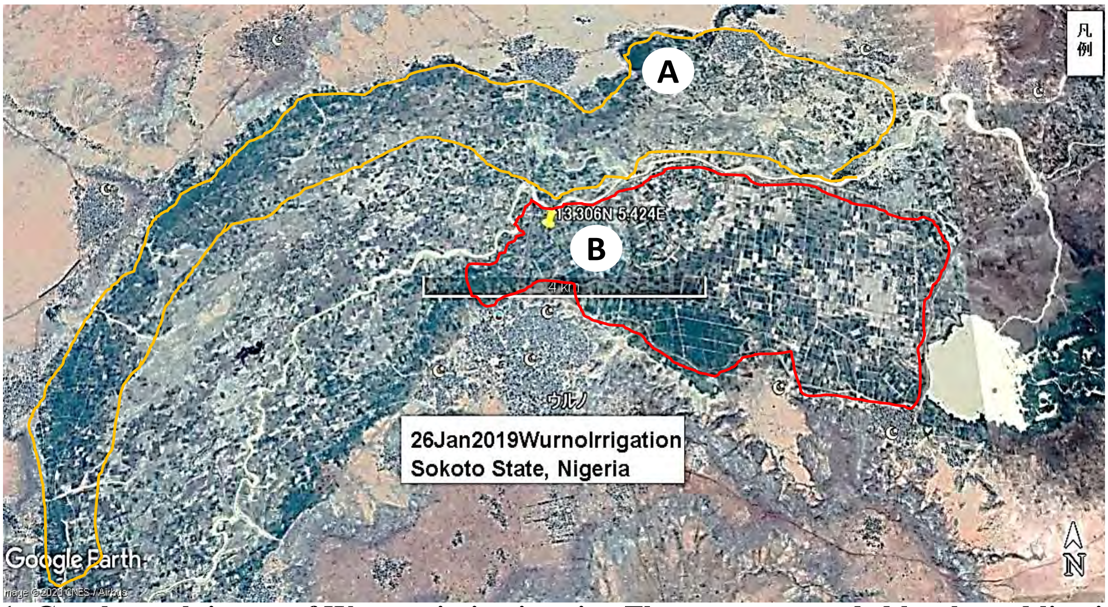
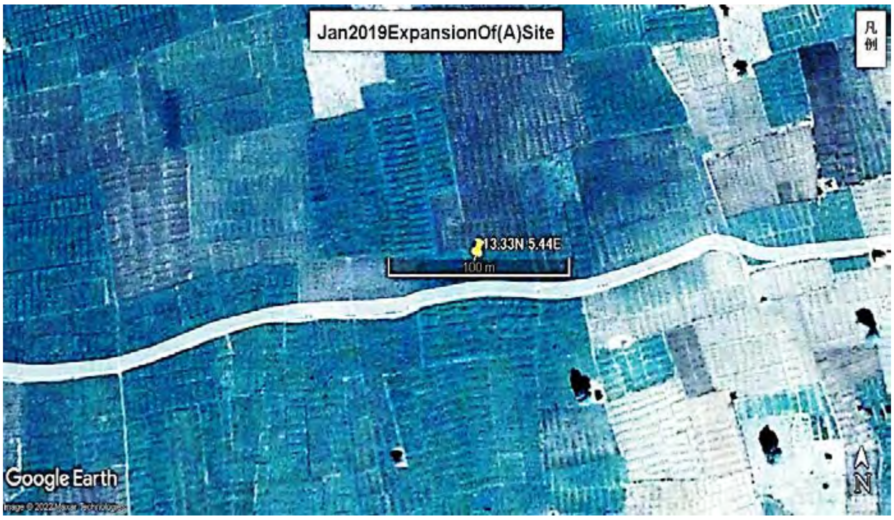


Figure 11: Google earth image of Wurono irrigation site. The area surrounded by the red line including (B) location is the official irrigation site, about 1200ha, which is located left bank (south) of the Sokoto river flood plain. The area surrounded by the brown line including (A) location is the farmer's mobile pump irrigation site, > 2500 ha. Figure 11A and Figure 11B are enlarged Google earth of (A) and (B) sites. The lengths of the central marker lines in Figures 11, 11A and 11B are 3km, 100m and 100m, respectively.



Figures 11A: Expansion of the location (A): 13.33N 5.44E, showing ridge rice cultivation platform of the farmer's rice platform along the Sokoto River flood plain. The white curve from east to west in the center is the farm road. Each farmer has a pump-irrigated rice field. Countless elongated sections are the ridges for rice cultivation, which are similar to the official irrigation sites shown Figure 11B below.

Figures 11B: Expansion of the location (B): 13.306N 5.424E, showing ridge rice cultivation platform of official irrigation schemes. The white curve from north east to south west in the center has the farm road, irrigation/drainage canal. The straight line shows major road.

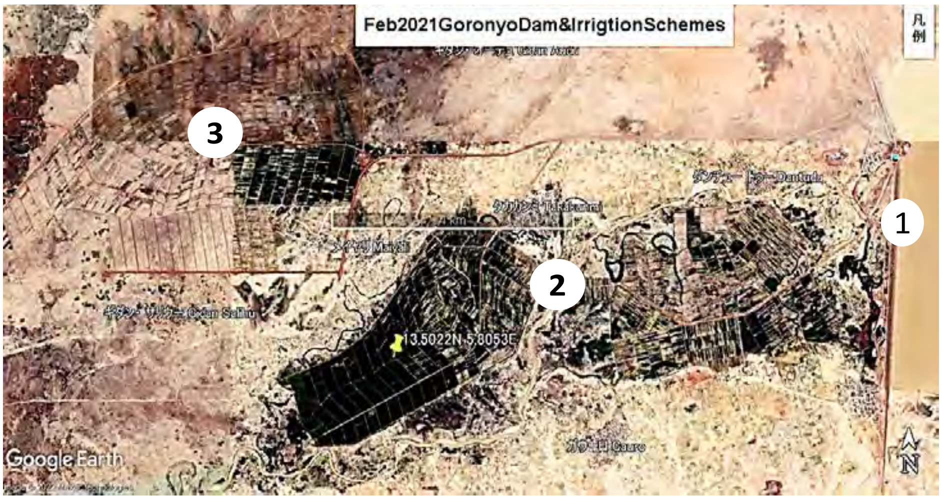


Figure 12: Panorama view of Goronyo official irrigation schemes of sites ② and ③ under the dam lake ①. The location of center of ② in 13.5022N 5.8053E.

The Goronyo Dam lake completed on 1984, which is a key structure that controls the Sokoto Rima river flood plains up to the junction of River Niger in Kebbi state (Zauro polder project). The estimated area of the irrigated (both official and farmers) rice farm is >100,000 ha. Areas ② and ③are on-going irrigation sites of about 5,000 ha. Rice cultivation started around 2012 in Site ② and around 2017 in Site ③.

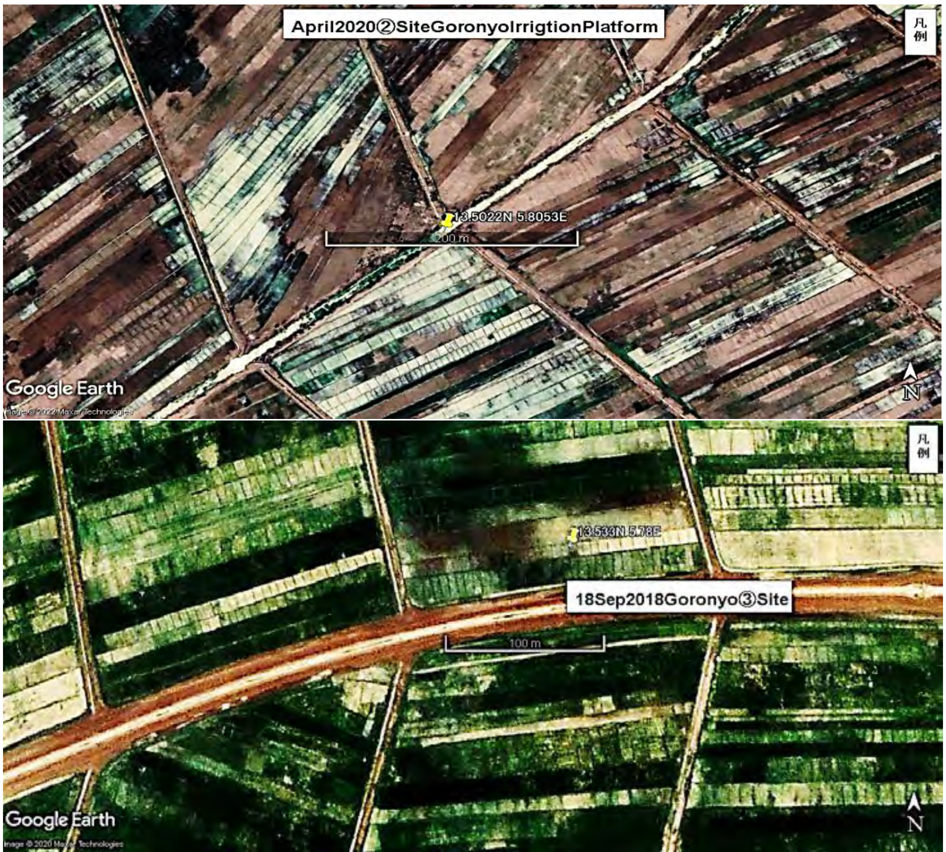


Figure 12A (upper) and Figure 12B (lower): Expansion of areas ② and ③ of Figure 12 respectively. Both ② and ③ farmers' rice cultivation platforms under official irrigation scheme are rudimentary micro sawah plots of 20–50 m^2 including some ridge rice cultivation platform.

2-9. Bakalori irrigation scheme of Zamfara State, Nigeria

Figure 13: Bakalori irrigation scheme, Zamfara State, Nigeria. (D) shows Bakalori dam lake. (E) shows expansion area (location 12.610N 6.057E) in Figure 14A and 14B. The central marker is 10km long

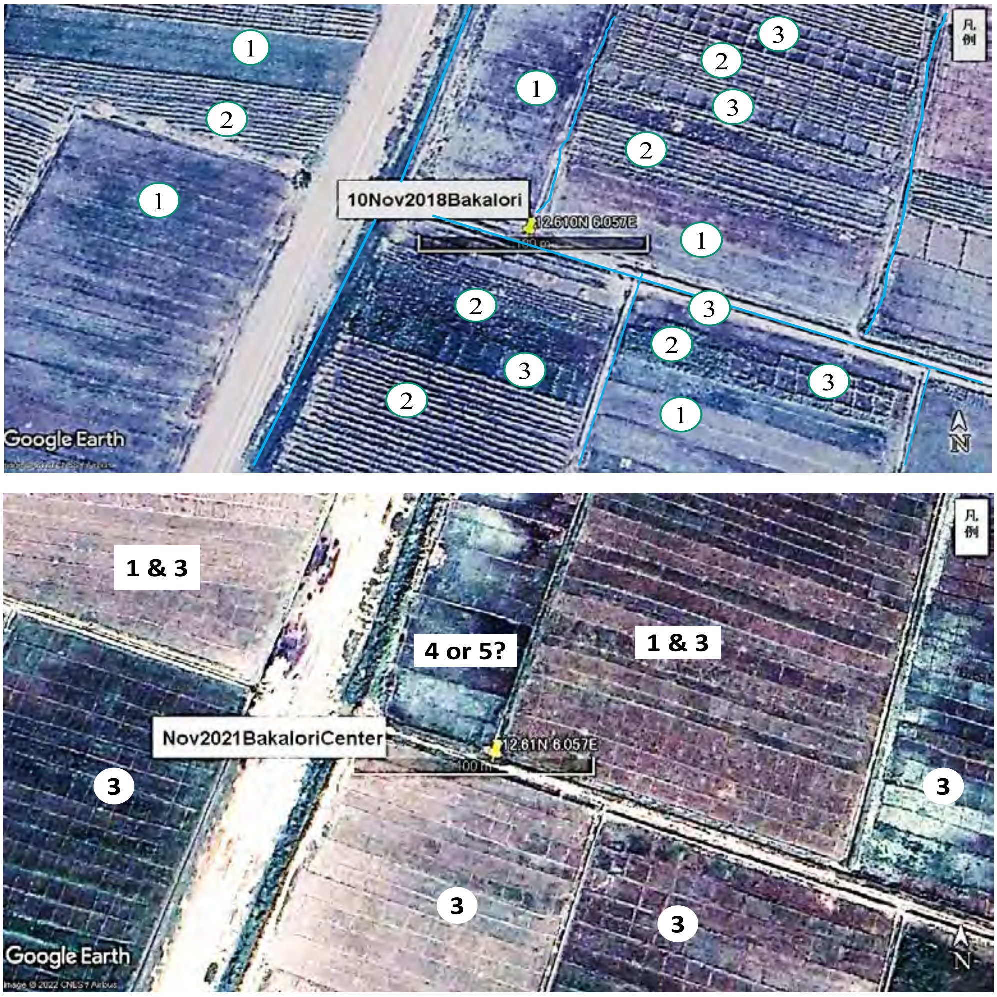


Figure 14A (upper) and Figure 14B (lower): Expansion of the area surrounded by a rectangular yellow line of the location coordinate of 12.61N 6.075E of Figure 13. The central marker is 100m long. The blue lines of Figure 14A (taken in 2016 image) indicate irrigation/drainage canals, which are somewhat improved but no special blue lines are made in Figure 14B (taken in 2021 image)

Bakalori Dam Lake was completed in 1981. Original plan was sprinkler irrigation for 15,000 ha and gravitational irrigation for 8,000 ha land had started in 1983 for rice, sorghum, wheat, onion, garlic, and tomato. Because of the structure and management of the system as well as agro-technological and sociocultural problems, the performance of this project has been poor. Sprinkler system was no longer operational by 2003. Since 2017, an improvement project of transforming irrigation management in Nigeria (TRIMING) with 7-year life span, which is supported by the World bank, has been underway : rehabilitation of 8,000ha and conversion/expansion of 6,000ha (Wikipedia 2022, Adelodun and Choi 2018).

As shown in two Google Earth images of Figures 14A and 14B, the central rice irrigation area of 8,000ha has similar platforms that are described so far in this section of 2, that is, Evolutional stages 1, 2, and 3 platforms that cannot accommodate modern science and GRT. Figure 14A of Google Earth image in 2016 has very diverse platforms: that is, ① the Sawah evolutional stage 1: Non-Sawah, no bunding, and no leveling, ② Ridge rice cultivation platform, and ③ Micro-Sawah platform. None of these platforms can accommodate GRT. Figure 14B of Google Earth image in 2021 has an impression of somewhat improved platform compare to the platform in 2016. But majority of the platform is ③ Micro-rudimentary sawah platform. It seems that some farmers have started to improve their platform to the level of ④ or ⑤ standard sawah platform as shown in the Figure 14B through the influence of Kebbi rice farmers and or training by NCAM sawah team as shown in Photo 49 below.

The photo No.49 of the Figure 18 shows a power tiller operation at the ③micro sawah platform fields at the Bakalori scheme. The length of the powertiller have about 3 m. This confirms the size range of farmers sawah plots are 3-5 m. It is our partner NCAM Sawah team that uses power tiller to demonstrate and train the skills how to prepare the standard sawah plots platform of stage to 4 or 5, which have larger plots for efficient use of agricultural machinery, leveling for water management, puddling, and etc.

Photo 49: Training on Sawah technology, to improve irrigated lands, by NCAM (National Center for Agricultural Mechanization) at Bakalori Irrigation Site under the transforming irrigation management in Nigeria project (TRIMING) (May 2019. Traditional Micro-Sawah plots, which can be seen in the upper half of the photo, are expanding and leveling with reinforced bunds

Photo 50: Good Agronomic practices including the System of Rice Intensification (SRI) can not works if a proper sawah system platform is not available. The majority of farmers cultivation land in Bakalori sites have not reached the standards platform. Therefore before introducing any good agronomic practices, there is needs the farmers lands to Sawah platform stages of at least 4 and 5.

Photo 49 shows the operation of a power tiller at the ③ micro-Sawah platform fields at the Bakalori scheme. The length of the power tiller is approximately 3m. This confirms that the size range of farmers' Sawah plots is 3–5 m as shown in Figure 14A and Figure14B. Our partner, NCAM Sawah team, uses a power tiller to demonstrate and train the skills for preparing the standard Sawah plots platform of stage 4 or 5, which have larger plots for efficient use of agricultural machinery, leveling for water management, and puddling etc. Photos 49 and 50 show that the any good agronomic practices (GAPs), such as the system rice intensification (SRI), can only be effective with the improvement of the farmers' cultivation platform,

2-10. Abandoned official irrigated projects: South Lake Chad and Lower Anambra in Nigeria

The green areas in Figure 15 show the distribution of the major irrigable lowlands in Nigeria. The iso-precipitation line of 500 mm, which shows the Sahel belt, extends near the border with Niger. There are many vast wetlands with about 500–1000 mm of annual rainfall, including the Lake Chad Basin. To date, we have been promoting the Sawah (eco-) technology, and it is only in Kebbi state, northwestern Nigeria (Figure 15), that the endogenous Sawah platform development by innumerable farmers has reached the scale of more than 100,000 ha, as described in the "Sawah Technology (6) Kebbi Rice Revolution".

2-10-(1). The South Lake Chad Irrigation Sites

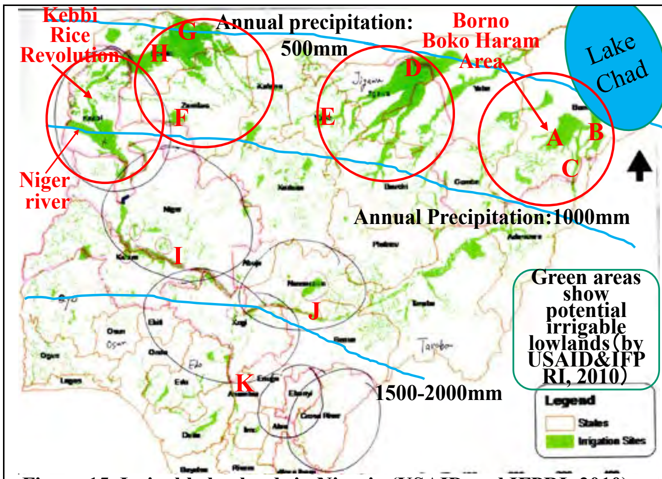
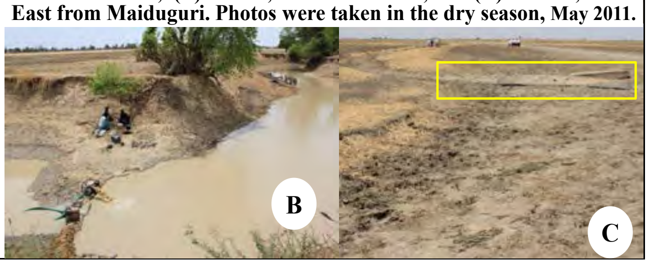


Figure 15. Irrigable lowlands in Nigeria (USAID and IFPRI, 2010)

Photo 51: Inland delta/flood plains in Borno State. (A): Dusuman, 10km Northeast, (B): Bama, 65km Southeast, and (C): Dikwa, 90km East from Maiduguri. Photos were taken in the dry season, May 2011.



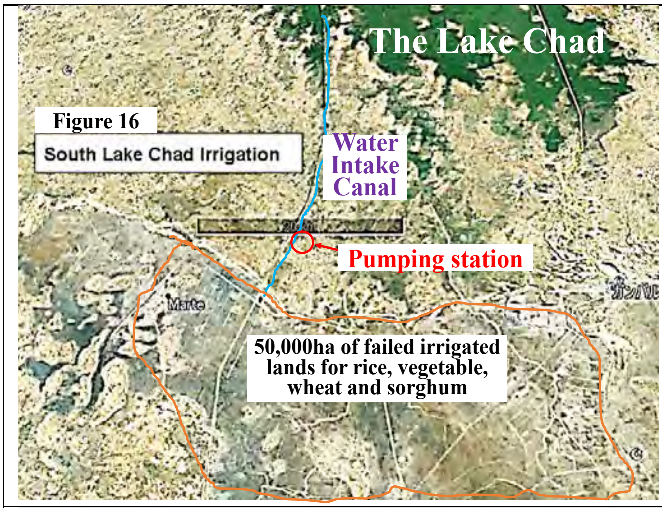


Photo 52: Faga pumping station, South Lake Chad Irrigation, August 1986

Photo 53: Mobile pump for irrigated vegetable and rice cultivation sites, Antul village area along Yazarem river, about 20km West from Dikwa. This site is the B site shown in the Figure 15. May 2011

Photo 54: Evolutional stages 1,2, and 3 (Non-sawah fields, ridge, and micro-rudimentary) sawah platforms observed in the south lake Chad project sites. Irrigation of these farmlands seems to be done by portable pumps. No crops cultivation between 2014 and 2019

Photos 51A shows the inland delta/flood plain near Dusuman, 10 km northeast of Maiduguri; 51B shows the Bama area, and 51C shows the Dikwa area. A small inverted wooden boat is shown in the yellow frame line of Photo 51C. These three photographs were taken in May 2011 at the end of the dry season. However, in August-November, river waters can flood about 1 m above the ground. In addition, even in the dry season, there is groundwater within 5 m underground, and as shown in Photo 53, rice and vegetables can be cultivated by irrigating with a small portable pump, similar to the flood plains in the Kebbi state.

Figure 15D-K show the locations of official large-scale irrigation sites developed by the Nigerian government and private company, that is, D: Hadeij (10,000 ha) in Jigawa state, E: Kano (15,000 ha), F: Bakalori (10,000 ha) in Zamfara state, G: Goronyo dam, and H: Wurno (5,000 ha) in Sokoto state, I: Edozhigi and Badeggi (5,000 ha) in Niger state; J: Olam farm (private company, 6,000 ha) in Nassarawa state, and K: Adani and Lower Anambra (5,000 ha) in Enugu and Anambra states.

Figure 16 shows the large-scale (50,000 ha) irrigation project site in the south of Lake Chad with a headrace of ≥ 30 km to the target area, which is indicated by the blue line. Photo 52 shows the large pumping station at Faga. It is a photograph taken at the position marked "Pumping station" in the center of Figure 16. The water level of Lake Chad did not rise, and hence, water could not be pumped out of the lake. This irrigation site is located in the areas shown in Figures 15A and 15B. It was developed under the technical guidance of Pakistan engineers at a cost of about 100 billion yen in the 1970s when Nigeria was still generating a lot of revenue from oil. However, the irrigation system was never effective, and the area is now abandoned due to Boko Haram terrorism. Photo 53 shows rice and onion cultivation using portable pump irrigation. This site is near Figure 15B. Photo 54 shows non-Sawah fields, ridges, or rudimentary micro-Sawah plots observed in the southern Lake Chad project sites in Figure 16. The irrigation of these farmlands seemed to be achieved using portable pumps. No serious crop cultivation was observed between 2014 and 2019 because of the Boko Haram disaster. The entire area can be irrigated using a small portable pump. Flood of about 0.5-1m (highest) and 1-2 months (longest) may occur during the latter half of the rainy season and early dry season. Even in the dry season, the groundwater is shallower than 5 m. It is a part of the wetlands leading to Lake Chad.

2-10-(2). Lower Anambra Irrigation Project

Figure 17 shows the original plan (4,000 ha) of the Lower Anambra Irrigation Project site in Nigeria. This is an ODA loan project of 22 billion yen (US$ 200 million) supported by Japan International Cooperation Agency (JICA)/Japanese Bank for International Cooperation (JBIC) in 1981–1991 when Nigeria was still generating a lot of revenue from oil. The project developed 3850 ha of an irrigated Sawah system platform for mechanized rice cultivation fields. JICA's technical cooperation was also implemented in 1989-1993.

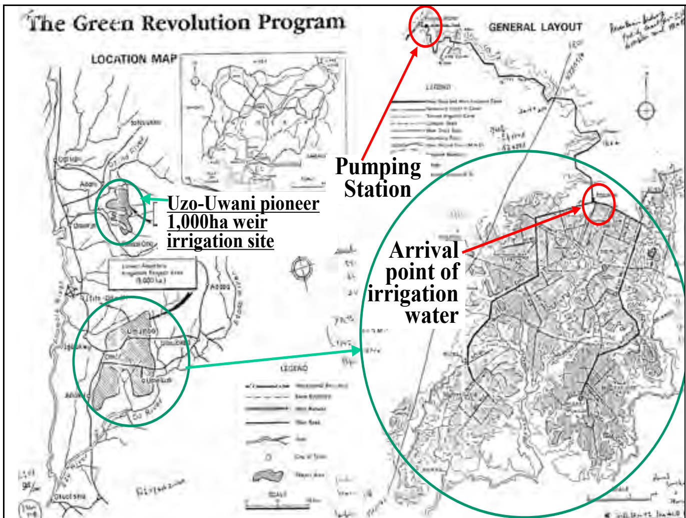


Figure 17. Lower Anambra irrigation project (1981-91) by Japanese ODA(3,850ha, Yen loan, 22billion Yen, about US$200million)

Photo 56A:(upper image) Pump station area. Photo 56B⑧lower image) Arrival area of irrigation water. The system failed in the late 1990s and continues to this day. The renovation works were initiated by Nigerian Government in 2019

The Anambra River flows at the top of the image shown in Photo 56A (upper), and the white square is the pumping station (location **6.615N 6.939E**). A large amount of irrigation water with a head difference of 30 m is pumped up to the main irrigation canal using a huge pump. Large amounts of electric power are continuously needed. The costs of quality maintenance were very high, and hence, the Nigerian government could not manage this station. The operation of the pump stopped within 10 years. The ODA loan debt was cancelled. Photo 56 (lower) shows the area of the main gate (location **6.5455N 7.017E**) of inflow irrigation water through the main canal 30 km from the pumping station. The blue lines with arrows indicate the main canal and inflow point of the Sawah system platform. The 3,850 ha of Sawah system platform, with an evolutionary stage 5, as of 1993, needs major improvement because of the degradation of the bunding system, leveling, and inlet/outlets of Sawah plots as well as main canal, secondary and tertiary canal systems. After a blank of more than 20 years, the Nigerian government began using the African Development Bank loan to repair the irrigation system, and the renovation may have been completed by March 2021. The completion was not confirmed in April 2022. The 1000ha Uzo-Uwani pioneer weir irrigation rice cultivation systems in Enugu state completed before 1985 also did not perform their initial target functions as of April 2022.

3. Why do poor paddy yields occur in the 1st, 2nd, and 3rd evolutionary stages of the Sawah system, that is, non-Sawah, ridge planting, and micro Sawah, which are common in SSA?

3-1: Tentative Definition of ① Micro-rudimentary Sawah plot (field), ② Small-section Sawah plot (field), ③ Standard Sawah plot (field), and ④ Paddy field (plot), which are shown in Photo 57A-57H.

The right side of Photo 57A shows a micro-rudimentary Sawah plots. The left side is a non-Sawah rice field, which is also "a paddy field". Photo 57B1, left side of Photo 57C, Photo 57E, and 57F are also micro-rudimentary Sawah platform. The right side of Photo 57C and Photo 57H are the standard Sawah platforms (Evolutional stage

4 and 5). Although there is no particularly clear criterion for Sawah plot size, Sawah plots of ≤ 50 m^2 size are tentatively defined as micro Sawah plot. If bunds are weak and small, which make impossible human to walk on the bunds without any damage of water control of the sawah plots, such plots are referred to as ① micro-rudimentary Sawah plots. However, plots with bunds that are strong and big enough to allow easy walking are referred to as ② micro Sawah plots or small Sawah plots.

Photo 57A: (Left) Red circled area is non-Sawah rice cultivation; (Right) yellow circled area is micro-rudimentary Sawah (Bida, 1987)

(Photo 57B1):Micro-rudimentary sawah plots, (Photo 57B2): Shallow tube well, and (Photo 57B3): Small pump irrigation. Sokoto river floodplain (13.114N 5.257E). Bunds and canal are poor and leaky. May 2011

Photo 57C: Micro-rudimentary Sawah (Left) and standard Sawah (Right), Nasarafu village, Bida, Nigeria, September 2004

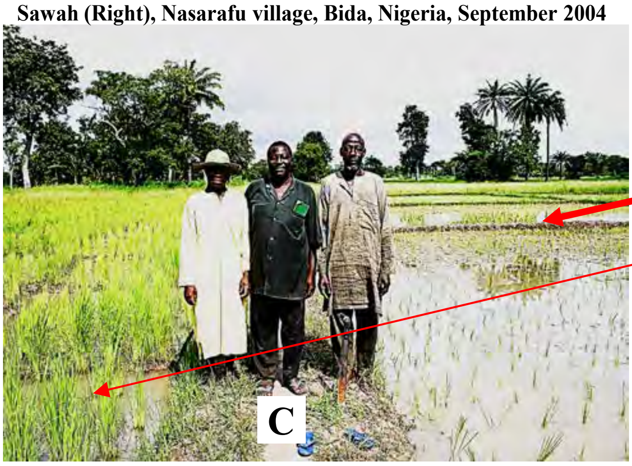


Photo 57D: Google earth image on 29, November, 2007, Nasarafu, Bida, Center position 9.002N 6.091E

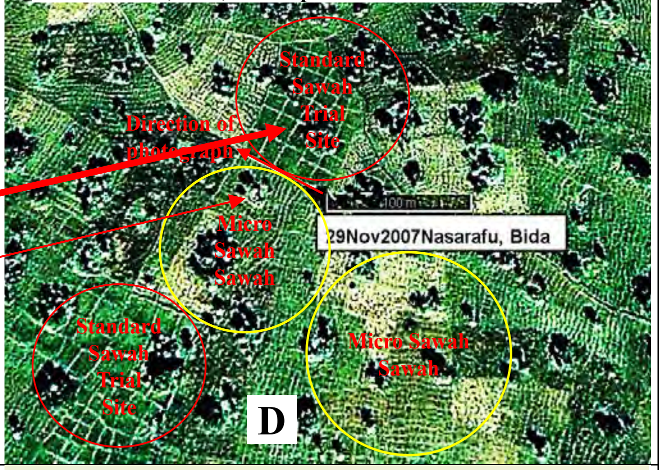


Photo 57E: Nupe's gravitational irrigation system with micro-rudimentary Sawah plots, Bida, Central Nigeria (September 2010).

Photo 57F: Irrigated lowland paddy fields or irrigated micro-rudimentary sawah plots (22nd August 1995). No integration of Fulbe grazing with Nupe rice farming

Photo 57G: Micro Sawah plots or small Sawah plots, irrigated by small pump, Zamfara river flood plain, Jega, Nigeria (May 2011), before Sawah Technology training. Location(12.1997N 4.3735E)

Photo 57H: Standard Sawah plots irrigated by small pump, at evolutional stages 4 and 5, Zamfara river flood plain, Jega, Nigeria (May 2011). Demonstration of Sawah technology and on-the-job training site. (Location 12.201N 4.3786E) Pump irrigation hose

Photo 57A-57H: Examples of Various Sawah platforms; Photo 57A, Non-Sawah and micro-rudimentary Sawah at Bida in 1987; Photo 57B1, micro-rudimentary Sawah, Photo 57B2, small pump forirrigatio, and 57B3, tube well, at Sokoto in 2011; Photo 57C, micro-rudimentary and standard Sawah at Nasarafu village (Bida 2004); Photo 57D, Google earth on 2007(location of Photo 57C and 57D is 9.002N 6.091E); Photo 57E, Shabamaliki village irrigation canal and micro-rudimentary Sawah, Bida; Photo 57F, micro-rudimentary Sawah and Fulani nomad at Gadza village, Bida, in 1995; Photo 57G, small Sawah, Jega (September 2011); Photo 57H, standard Sawah demonstration site at Jega, Site 1 (May 2011).

The ③ standard Sawah plots (platform) have the following characteristics. The plots have irrigation and drainage facilities, and their size is normally > 50 m^2. The surrounding bunds are strong, big, and compacted, making it easy to walk and prevent water leakage. Each Sawah plot surface soil is puddled (normally) and leveled within a 10 cm (±5cm) height difference in a plot. Thus, standard rice planting practices are possible. All the rice fields: ①Micro-rudimentary Sawah plot (field), ②Small-section Sawah plot (field), ③Standard Sawah plot field (evolutional stages 4 and 5)), and ④ paddy field (plot) shown in Photos 57A–57H are paddy fields. Thus, as long as we use the term “paddy fields,” we cannot distinguish the aforementioned various rice fields (plots or platforms) (①-④ as shown in Photos 57A-57H). Thus, the term “paddy” cannot be defined scientifically, at least in SSA.

3-2: Why do SSA farmers not improve their farm productivity under the 1st, 2nd and 3rd evolutionary stages of the Sawah system platform?: a discussion from the viewpoint of actual farm work

(1) Sawah Hypothesis 1 explains why non-Sawah fields cannot realize the genetic potential of rice variety, which is explained in ‘Sawah Technology (3) Principles and Theory’ in detail. In addition to non-Sawah fields, the evolutionary stage of the Sawah system, that is, the size and quality, especially the leveling quality of each Sawah plot, are also important for controlling water.

(2) Yield cannot be improved in rudimentary micro/small Sawah plots because of the following reasons. First, there is a problem with the utilization efficiency of land space. As the space between the rice plant increases, the space that cannot be used for planting increases. An example is shown in the figure below. Assuming 1 m long bund occupies 1 m^2 of non-planting space, the rice field occupies 64% of the area per hectare in a micro-Sawah plot of 9 m^2 (3 × 3 m section) size. When the area of one Sawah plot is 40 m^2 (6.3 x 6.3 m section), the occupancy rate of the area that cannot be used for planting becomes 32 %, and the loss space will be 16 % in Sawah plot of 160 m^2 (12.5 x 12.5 m section). At 625 m^2 (25 × 25 m section), 2500 m^2 (50 × 50), and 1 ha, the loss space is 8 %, 4 %, and 2 %, respectively.

(3) In terms of agronomic management problems, modern agricultural science and technology cannot be

effectively used in micro-Sawah plots. Originally, this micro-Sawah plot system is a farming method, with hoe being the main agricultural equipment; hence, some activities, such as animal traction and power tiller operation becomes extremely inefficient.

(4) The results obtained by the researchers in a small experimental plot of approximately ≤ 10 m^2 cannot be applied to a farmer's field ≥ 1 ha. For example, water management of each bunded Sawah plot can be achieved through the management of water leakage from the bunds, management of permeability of soil layers, management of leveling of rice field surface, and management of irrigation and drainage to drainage. Therefore, when the size of one Sawah plot is less than 40 m^2, farmers need to manage Sawah plots over 250 plots per ha, but it is almost impossible to appropriately perform the water management as described for each plot. Moreover, when the Sawah rice plot size is > 200 m^2, the number of Sawah plots that need to be managed per ha is ≤ 50, and careful water management becomes possible.

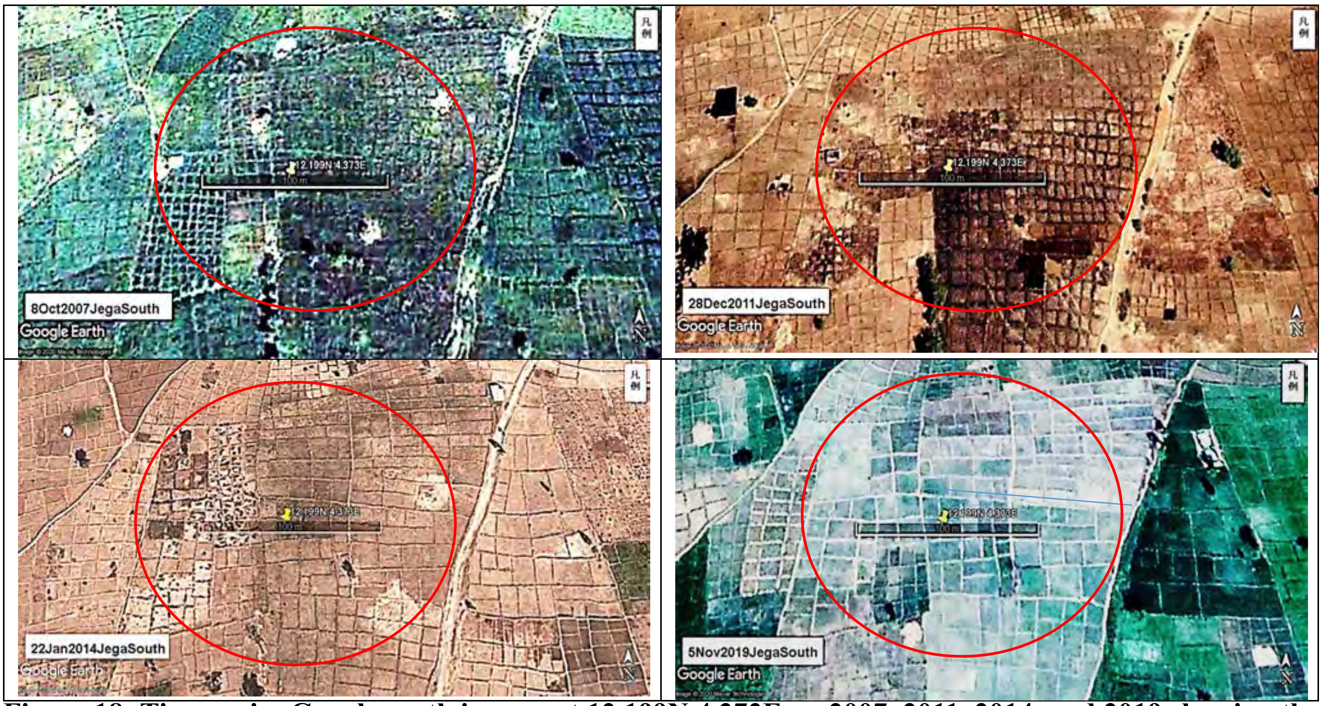


Figure 18: Time series Google earth images at 12.199N 4.373E on 2007, 2011, 2014, and 2019 showing the evolution of Sawah system platform on the Zamfara river flood plain. Mean area of Sawah plots was about 30 m^2 in 2007–2011 (evolutionary stage 1–3), while mean area has been expanding about 150 m^2 with strong bund and possible improvement of plot leveling (evolutionary stage 4 and/or 5) in 2014–2019.

Figure 18 shows an example of the improvement of Sawah plot size observed in 2007-2019 at Jega area in the Zamfara river flood plains, Kebbi state, Nigeria (Central position of the Google image is **12.199N 4.373E**). As shown in the Google earth image in 2007 and 2011, the major rice cultivation platform was micro-rudimentary Sawah of evolutional stage 3, with plot size range of 20–40 (mean about 30) m^2. Please see the red circled area, of which the marker length is 100 m. In 2007, almost all sawah plots had evolutional stages of 1-3, but in 2011 they were 2-3, with plots becoming clearer, bunds stronger, and larger in size. In 2014, almost all the lands are covered with standard sawah plots of evolutional stage 4, with plot size range of 50–200 (mean about 150) m^2. This Sawah system evolution started after March-December 2011, when trainings and demonstrations on the Sawah technology were conducted by the team of NCAM/Kinki University supported by JSPS and the World bank's "Fadama project" (details are in separate report in "Sawah Technology 6: Kebbi Rice Revolution, Nigeria", and World bank 2016). The standard Sawah system platform was expanded in 2012–2019. The diversity of the patterns of Sawah plot parcels as seen in the Google earth image clearly shows that these Sawah fields improved endogenously by the self-help efforts of the farmers who own each land.

The four photos shown in Figure 19 compare the ridge and standard Sawah rice platforms, the evolutional stage 4, at the Sheshi Bikun village (8.898N 6.091E), where the two platforms are side by side. In the case of ridge cultivation, three aforementioned problems in the micro-Sawah rice cultivation platform appear more severely.

Please also see Figures 10A and 10B as well as Photo 48 and Photos 49① and Photo 49② for the Edozhigi irrigation scheme at Bida, Niger State, Nigeria. The creation of myriad ridges results in a loss of physical planting space, similar to the micro-Sawah fields. In addition, countless bunds/ridges bring about the same effect as creating countless partitions, making efficient water management virtually impossible.

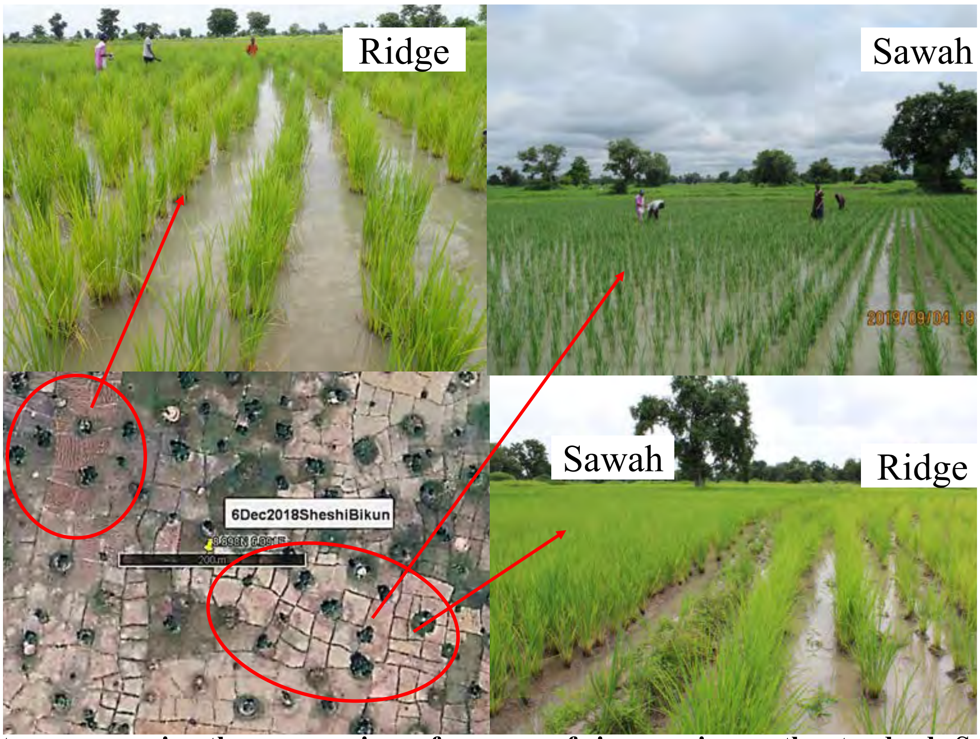


Figure 19. Pictures comparing the agronomic performance of rice growing on the standards Sawah platform and traditional ridge rice platform, which can be observed at Shishi Bikun, (GPS position 8.898N 6.091E) side by side (September 2019).

Figure 20. Google earth image of the location at 13.115N 5.259E area of the Rima River flood plain about 5 km north of Sokoto city taken on April 2020.

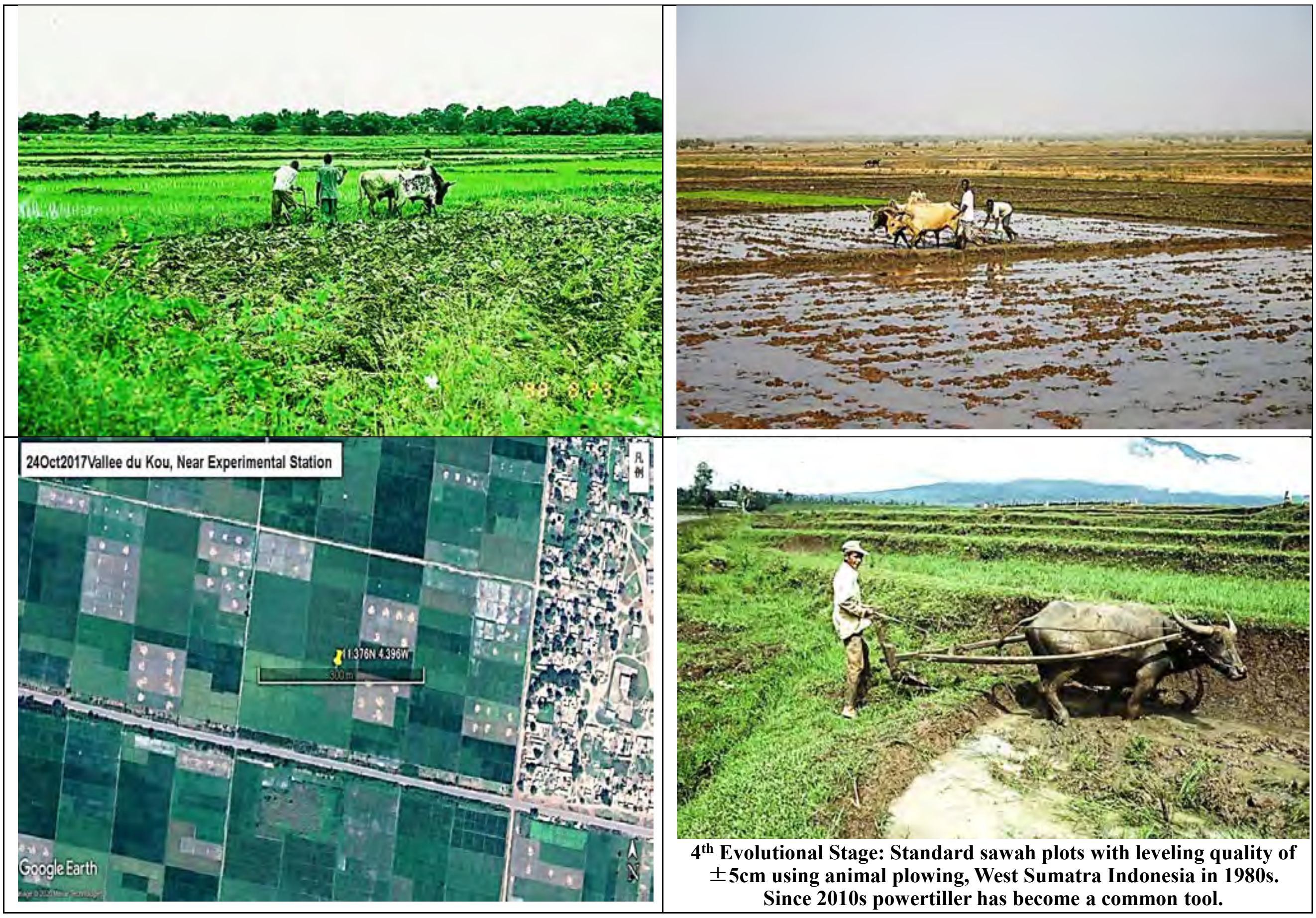
Figure 20 shows the Google Earth image, taken in April 2020, of the location at the **13.115N 5.259E** area of the Sokoto River flood plain, about 5 km north of Sokoto city, Sokoto State, Nigeria. This is adjacent to Kebbi state and is the upstream location of the Rima River. As shown in Figure 20, unlike in Kebbi state, ridge cultivation is the most popular rice cultivation platform at both the government's large-scale irrigation project site (Figure 11A and Figure 11B) and on farmers' small portable pump irrigation sites (Figure 57B is an example), in Sokoto state, even as at April 2020. It is very difficult to realize paddy yields > 3t/ha under this ridge rice cultivation platform. Figure 20 is the Google earth image of the location at 13.115N 5.259E area of the Rima River flood plain about

5 km north of Sokoto city taken on April 2020. Sokoto state, Nigeria is adjacent to Kebbi state and is the upstream location of the Rima river. As shown in the Figure 30, unlike Kebbi state, the ridge cultivation is the most popular rice cultivation platform at both on the government's large-scale irrigation project site (Figure 12-15) and on farmers' small portable pump irrigation sites (Figure 57B2 is an example) even at April of 2020. It is very difficult to realize the paddy yield higher than 3t/ha under this ridge rice cultivation platform.

4. Irrigated Sawah Platform: Evolutional stage 4-5, which accommodate various green revolution technologies

4-1. Sawah platform evolutional stage 4: Irrigated standard Sawah system platform with appropriate Sawah plot size 50–200 m^2 with standard bunding to regulate water leaking and leveling quality to ±5 cm/plot. It could be manual cultivation or animal cultivation, and the total rice cultivation is less than 2ha/season/family farm

(Note on tentative definition and examples)
Evolutional stage 4: Figure 21 shows the animal plow operation (left photo taken in August 1998) and leveling and puddling operations (right photo taken in February 2006). Both photos were taken at Vallee du Kou, Burkina Faso. The GPS position is approximately 11.376N 4.296 W, and the Google Earth image in October 2017 is shown below the photo in August 1998. The site was developed by Taiwan team in 1969 as described in the next section 4-3 “Pioneer of international cooperation for standard irrigated rice cultivation in Africa: Taiwan team”



4th Evolutional Stage: Standard sawah plots with leveling quality of ±5cm using animal plowing, West Sumatra Indonesia in 1980s. Since 2010s powertiller has become a common tool.

Figure 21. Sawah platform of evolutionary stage 4, which has co-evolved with animal plow cultivation.

4-2. Sawah platform evolutionary stage 5: Irrigated standard Sawah system platform good for appropriate mechanization, such powertiller cultivation. Sawah plot size is generally > 100 m^2 and standard bunding to control water leakage, and the leveling quality is ±5 cm per plot. Total rice cultivation area can be more than 2ha per season per family.

The two photos at the down left, photo 58, in Figure 22 was taken at Biemso No.1 inland valley, Ghana (6.8815N 1.847W), August 2000, and the photo 57H at the down right was taken at the Zamfara River flood plain, south of Jega town, Nigeria (12.201N 4.3785E).

Photo 58 (5th stage): Standard sawah plots with leveling quality of±5cm. Bush inland valley was developed by farmer using powertiller, August 2000, Biemso No.1, Ghana (6.8815N 1.847W)

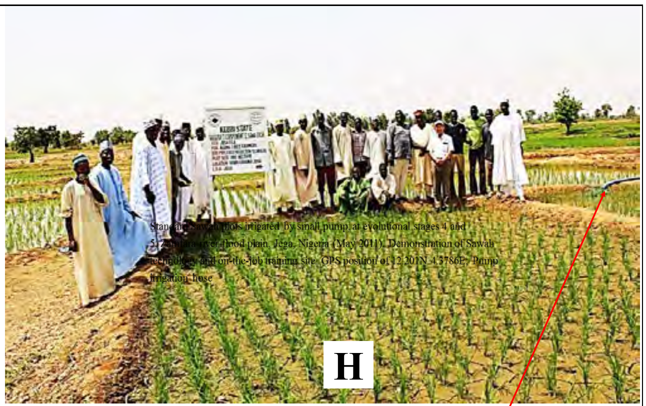


Photo 57H: Standard Sawah plots irrigated by small pump, at evolutional stages 4 and 5, Zamfara river flood plain, Jega, Nigeria (May 2011). Demonstration of Sawah technology and on-the-job training site. (Location 12.201N 4.3786E) Pump irrigation hose

Figure 22. Sawah Platform of evolutionary stage 5, which has co-evolved with tractor cultivation.

4-3. Pioneer of Asian and African international cooperation for standard irrigated Sawah platform for rice cultivation in Africa: Taiwan team

Mr. Yoichi Hatta, a Japanese government engineer who was the leader to complete 150,000 ha of irrigated Sawah platforms in the Jinan Plain of Taiwan in 1930. Completed about 100 years ago, this project has been the basis for the development of friendly relations between Japan and Taiwan as of 2020 (Lee. 2003, 2015). After about 5 years of independent wars, most Asian countries achieved independence from the colonial rule of Western countries by 1950. Following the independence of Asian countries, especially after the Asia-Africa conference held in Bandung, Indonesia in 1955, many SSA countries also achieved independence around 1960. Whatever the reason, World War II ended colonial rule and promoted the independence of Asian and African nations.

Immediately after the independence of these African countries, Taiwan implemented large-scale international cooperation for irrigated Sawah platform development throughout Africa in 1961–1975 and 1995–2018, (Figure 23 and Table 1). Taiwan, which had a population of only 12 million at that time, selected 25–35-year-old technicians by public recruitment, and after 1–2 years of training, 1200 experts were dispatched to 24 SSA countries. About 60,000 SSA farmers, extension officers, and engineers were trained on the job. As shown in Table 1, irrigated Sawah platforms with a total area of 27,392 ha were developed (Note: the data on Libya and Mauritania are excluded in Table 1 because of the minor activities in the two countries, and if we include the data of the two countries, the total area becomes 28,830 ha). Dispatched Taiwanese experts formed a platoon of 5–10 young experts of age 25–35 years under the team leaders of age 40–50 years, stationed in rural areas in SSA for 2–3 years, who trained farmers to carry out the irrigated Sawah system development and rice cultivation. This activity seems to have formed the basis for Sawah-based rice cultivation, which is progressing throughout the current SSA.

Taiwanese youth have been dispatched to SSA as a part of the peaceful democratic fight for the existence of a nation of Taiwan under the United Nations system. This was one of the means to win the United Nations Orthodox War in the United Nations between Communist-controlled China on the continent and democratic China on Taiwan Island (Wakatsuki and Hsieh 2003, Hsieh 2001 and 2003). Taiwan fought for hegemony in the United Nations with mainland China. Subsequent agreements with China, which have acquired diplomatic rights, have prevented SSA countries from assessing Taiwan's activities. For this reason, Taiwan's activities are buried in the history of SSA countries. Sawah system platforms and dams developed at that time still remained throughout the 22 countries listed in Table 1. These are available on Google Earth, even now, in 2021. The details of fact confirmation by Google Earth images are described in Sawah Technology (3-1) and Sawah technology (3-2) for Cote d'Ivoire, Ghana, Togo, Benin, Cameroon, Rwanda, and Malawi, as well as in Sawah Technology (3-3) for Burkina Faso, Senegal, Niger, Guinea Bissau, Gambia, Sierra Leone, Liberia, and Democratic Republic of the Congo.

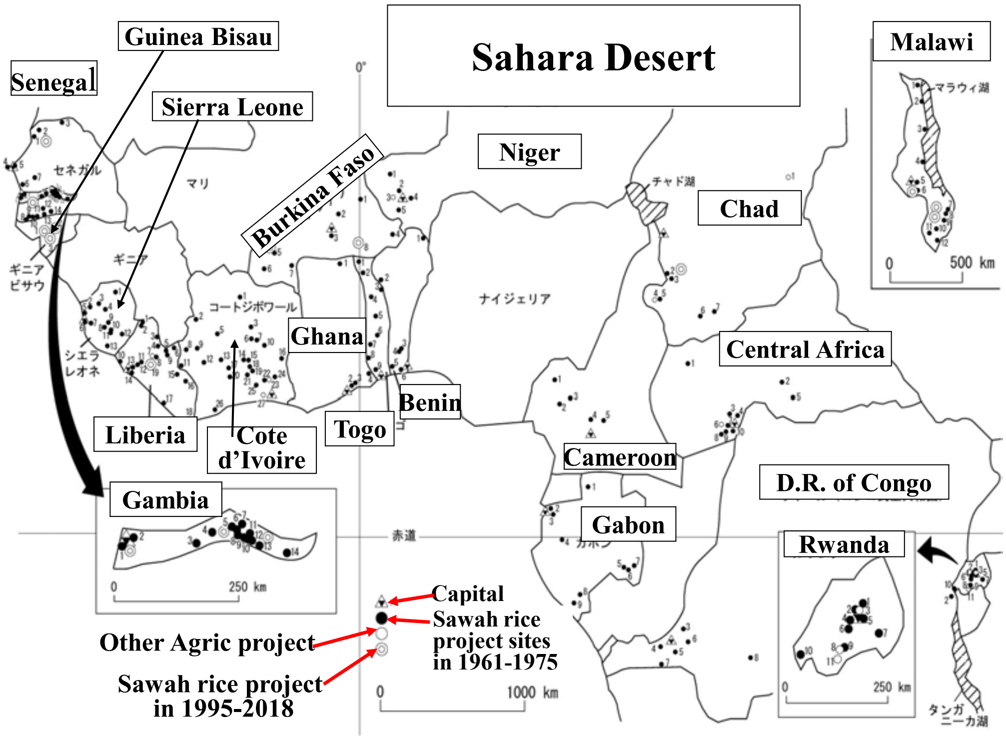


Figure 23. An overview of the development, training, and technical cooperation for the promotion of irrigated Sawah rice cultivation carried out by the Taiwan team in 24 SSA countries in 1961–1975 and 1995–2003.

Table 1. Summary of Taiwan assisted irrigated Sawah (Paddy) platform developemnt in 22 African Countries in Phase I (1961–1975) and Phase II (1990–2003) (Wakatsuki and Hsieh 2003, Hsieh 2001, 2003).

Country	Irrigate Sawah(Paddy) area developed (ha)	No. of farmers trained	Irrigation canal (km)	Drainage canal (km)	No. of Dam	No.of pumping Station
Botswana	44	252	6.7	3.7	5	10
Burkina Faso (Phase I)	1296	4560	89.3	57.9	1	0
Burkina Faso (Phase II)	1150	1100	No data	No data	No data	No data
Cameroon	209	772	28.6	16.3	36	1
CentralAfricanRepublic	153	775	36	7.8	4	18
Chad	578	1756	69.6	34.9	0	4
Benin	782	1621	62.7	83.5	3	6
Gabon	257	571	39.3	44.9	0	27
The Gambia (Phase I)	1372	8643	130.3	20.1	1	172
The Gambia (Phase II)	1923	5206	No data	No data	No data	No data
Ghana	108	374	13.1	11.5	1	1
GuineaBissau(1990-98)	3708	3681	No data	No data	No data	No data
Cote d'Ivoire	5475	3384	1000.8	619.9	161	0
Kingdom of Lesotho	133	3314	26.8	11.9	7	8
Liberia (Phase I)	845	2790	93.1	139.2	10	5
Liberia (Phase II)	260 (planned)	5000(planned)	No data	No data	No data	No data
Madagascar	190	97	12.6	16.3	7	1
Malawai (1966-2008)	1383	1295	132.2	149.7	1	4
Niger	1569	8620	680.7	44.7	0	25
Rwanda	821	4246	164.1	122.3	0	0
Senegal (Phase I)	817	3870	34.3	19.9	10	18
Senegal (Phase II)	2400(rehabil. include.)	No data	No data	No data	No data	No data
Sierra Leone	117	1307	18.1	11.1	6	12
Kingdom of Eswanti	106	No data	16.7	9.7	0	2
Togo	284	3124	48.2	33.7	3	8
DR Congo (Zaire)	550	6482	78.6	64	8	12
Total Phase I	17088	57853	2781.8	1522.7	263	334
Total Phase II	10304	16282	132.2	149.7	0	0

5. Evolutional stages 5 and 6 Sawah platforms for mechanized farming: Stage 5: lowland irrigated Sawah platform with a plot size > 1000 m^2 as well as good bunding and leveling quality < ± 5cm. Power tiller and/or small-tractor cultivation. Stage 6: Tractor-based advanced irrigated Sawah platform with a plot size > 1000 m^2. Good bunding, leveling quality < ±2.5cm using lasar leveler. Separation of irrigation and drainage canals.

5-1. Large-scale irrigated Sawah system platform by Olam Co. Ltd, Nigeria: evolutional stages 5 and 6 (large-scale Sawah plot and laser leveler tractor).

Photos 59-64 shows irrigation project on the Benue River floodplain in operation as of February 2022. As shown in **Photo 59,** the total area of the high quality irrigated Sawah platform, stage 5 and 6, is 5,000 ha. The central marker is 8km long. **The (C) center position is 7.90N 8.317E.** Annual paddy production can reach 40,000 tons if full double rice cropping can be realized. This irrigated rice farm was developed by Olam Co. Ltd, a private large-capitalized company. There is also farm airport and a huge rice mill (M). **Photo 60** shows the pumping station, which is indicates as (P) point in photo 59. Water is taken from the Benue River. The Benue River originates from the Cameroonian forest area. **Photo 61** shows one of the main irrigation canal on the way from the (P) point to (FD): flood damaged point as shown in **Photo 62.** The (FD) point shows flood damaged area, which was under repairing and construction of the waterways and sawah system platforms. Four photos of 61-62 and 63D were taken on August 2016. Since this area is located downstream of the Benue River, the destructive power of flooding is great. Therefore, Olam has difficulty developing and maintaining the irrigation system. As you can see from **Photo 63A**; the Google image taken in December 2010, full-scale field development of Sawah (paddy) began around this time. As can be seen from **Photo 63B**; the image in January 2014, it is believed that a laser leveler tractor was used to increase the leveling quality in large-sized Sawah plot of ≥ 10–20 ha, and rice were directly cultivated in Australian or American-style irrigated rice fields. Direct seeding was performed (**Photo 63D**) by using an airplane or tractor. Pesticide spraying was also performed by an airplane or tractor (August 2016). However, in the Google image taken in January 2017(**Photo 63C**), the plots were subdivided into units of ≤ 1–5 ha to facilitate water management in the Sawah plots. The Sawah plots near the (C) area observed by the authors (Wakatsuki and Ademiluyi) in August 2016 (**Photo 63D**) had a larger plot of size 10–25 ha, but the leveling quality seemed to be a standard level of ± 10 cm in a plot using laser leveler tractors. In August 2016, according to photographs taken near this area (C) and the explanation of the field agronomist, the initial growth of rice in the direct-seeded Sawah plot needs good water management methods to enhance the initial growth and increase the number of tillers to control weeds. However, in addition to the use of herbicides at the appropriate time, it is necessary to hire several farmers to perform manual weeding operations. Weed management is exceedingly difficult in direct sowing cultivation, especially during the wet season (**Photo 63D: expanded**). The most recent Google Earth **Photo 63E** on February 2022, which is the same location of Photo 63D, indicates sawah platform is further improved. The evolutionary stage of the Sawah plots is considered to be 6. As shown in **Photo 64**, (M) point indicates rice milling factory, which had 36,000 tons of rice milling capacity annually in 2014, and workshops for various heavy machines. Olam Co. Ltd reported that the total rice milling capacity in Nigeria reached 240,000 tons by 2020. Olam also trained rice farmers to secure paddies for milling. In Nigeria, it seemed that such private companies are forming a value chain for rice cultivation, with Thai-style rice millers at the top, by entrusting them to rice farmers. This means Olam will promote the Thai style, miller-led, and small out-grower farmer-based rice cultivation in Nigeria.

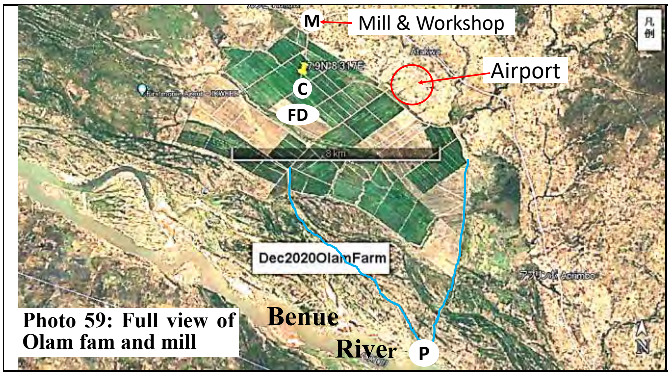


Photo 59: Full view of Olam fam and mill


Photo 60: (P) Pumping station at Benue river flood plain (August 2016)

Photo 61: (P) Main Irrigation Canal (August 2016)

Photo 62: FD point; Flood damage and repairing area (August 2016)

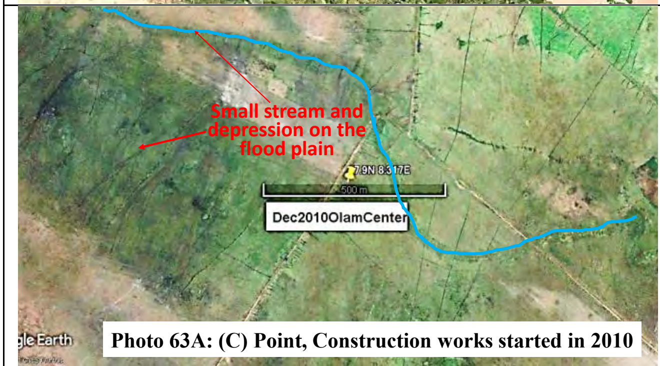


Photo 63A: (C) Point, Construction works started in 2010

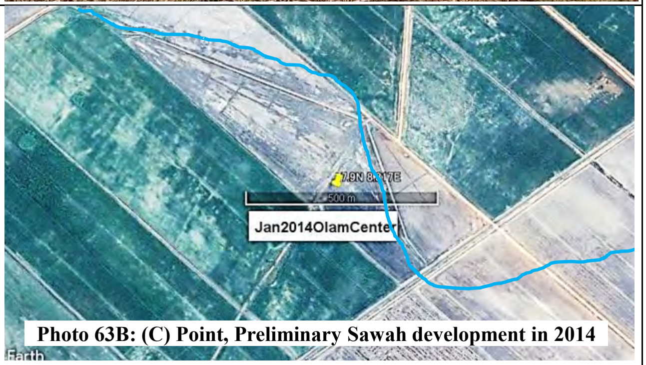


Photo 63B: (C) Point, Preliminary Sawah development in 2014

Photo 63C:(C) Point, Sawah Platform Improvement in 2016

Photo 63D: (C) Point; August 2016

Photo 63D:Expanded; Rice & Weed

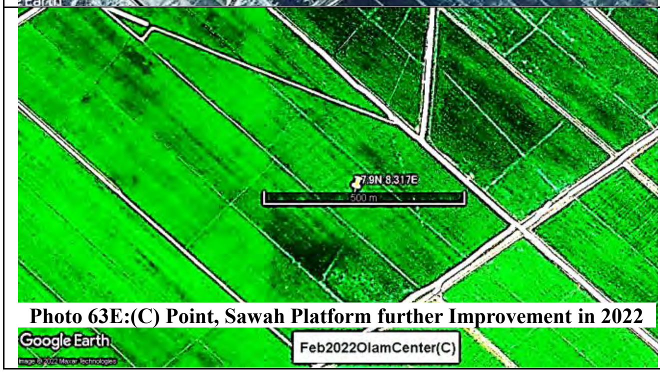


Photo 63E:(C) Point, Sawah Platform further Improvement in 2022

Photo 64:(M) Milling factory and heavy machines (August 2016)

5-2. Kebbi Rice Revolution: a model of sustainable endogenous rapid development of stages 4–5 irrigated Sawah platform

The Kebbi Rice Revolution is the main issue of Sawah Technology (6), and hence, the authors will briefly describe only the following main points. Could farmers in the Kebbi state have increased in just 10 years, 2010 to 2020 and could the annual rice cultivation area and paddy production have increased from 50,000 ha and 100,000 tons, respectively, in 2010, to 250,000 ha and 1.5 million tons of paddy production, respectively, in 2020? Olam Co. Ltd. has newly developed 5,000 ha of irrigated Sawah platform and realized an annual paddy production of 40,000 tons, which is considered to a successful example of rice cultivation promotion in Nigeria (Ademiluyi et al. 2021). The authors want to compare the impact of innumerable farmers' new self-help techniques for irrigated Sawah platform development and Sawah-based rice farming implementation with the impact of large capital, such as that provided by Olam Co. Ltd. This comparison can be useful for formulating strategies to promote rice cultivation in the future. For example, can the results of this Kebbi Rice Revolution approach extend to other northern states of Nigeria with similar ecological environments? Or is it applicable to other Sahelian countries with similar ecological environments, especially Chad and South Sudan, where suitable land for irrigated Sawah platforms for rice cultivation is distributed in ≥10 million hectares? This will be described in detail in Sawah Technology (5): Practices and Potential, and (6): Kebbi Rice Revolution, Nigeria.

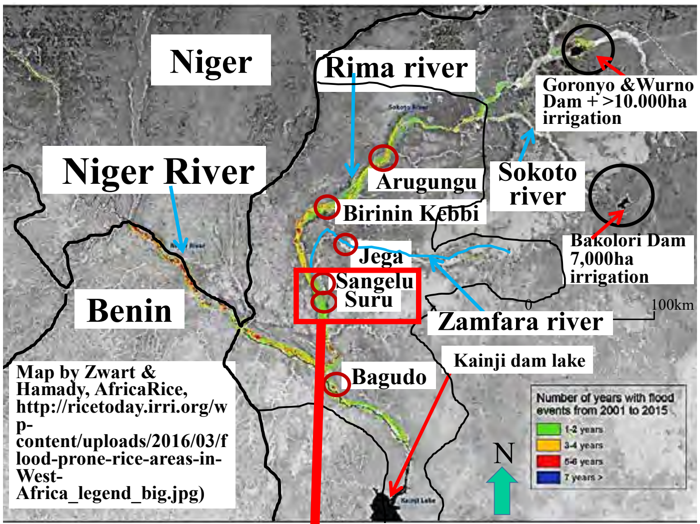


Figure 24. Map showing major flood plains and delta in Kebbi state

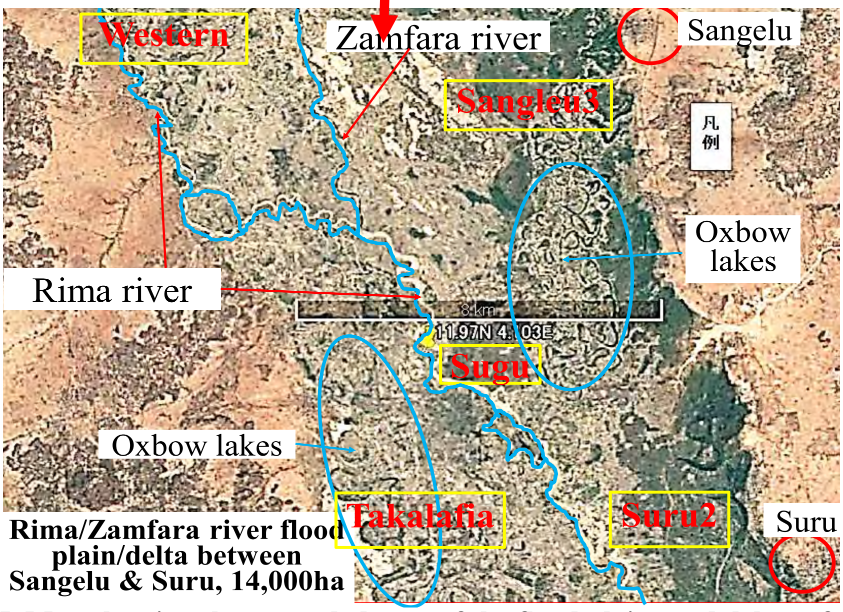


Figure 25. Map showing the expanded area of the flood plains and deltas of the Rima river and the Zamfara river between Sangel and Suru areas of Figure 24

Figure 24 shows the floodplains of the main rivers in Kebbi state, that is, the Rima (Sokoto), Zamfara, and Niger Rivers (Zwar and Hamady 2016). Activities to implement Sawah Technology were conducted mainly in 2010–2012 at the six major rice-growing areas of Argungu, Birinin Kebbi, Jega, Sangelu, Suru, and Bagudo in Kebbi state, which are indicated by six red circles. These activities were conducted based on the MOU with the World Bank and NCAM/ Kinki University's KAKENHI (JSPS's specially promoted project in 2007-2011, Wakatsuki 2012, 2017a, 2017b, and 2017c). The total potential area of the flood plains/deltas, where rice can be cultivated is approximately 500,000 ha. The areas painted in red in the floodplains /deltas have some risk of flood damage during the rainy season. However, flood damage can be avoided in crops grown in the dry season, which have expanded rapidly since 2013. Moreover, it is possible to cultivate a second crop in the dry season. Figure 25 shows the Rima/Zamfara River floodplain/delta between Sangelu and Suru, where the brown areas are uplands. The gray and black-green areas are deltas and floodplains, which total area is 14,000 ha in the range of this Google Earth photo. The black and green areas indicate that rice is planted even during the dry season. Google photos were taken at the end of January; hence, the dry season crop area might further expand from February to March.

Figures 26–29 show expanded Google Earth images of the five yellow and red colored areas, that is, Fig. 26 for Sugu, Fig. 27 for Western (end of Sangelu) and Takalafia, Fig. 28 for Sangelu, and Fig. 29 for Suru, respectively, in 2010–2020. As shown below, during 10 years, farmers have developed 290 ha (53 % of 550 ha) at Sugu, 24 ha (15 % of 160 ha land) at the Western (end of Sangelu), 44 ha (27.6 % of 160 ha land) at Takalafia, 70 ha (87.5 % of 80 ha land) at Sangelu, and 74 ha (92.5% of 80 ha land) at Suru sites. Within each Google earth photos, the areas where the sawah platform was developed are shown in white and sawah areas were measured.

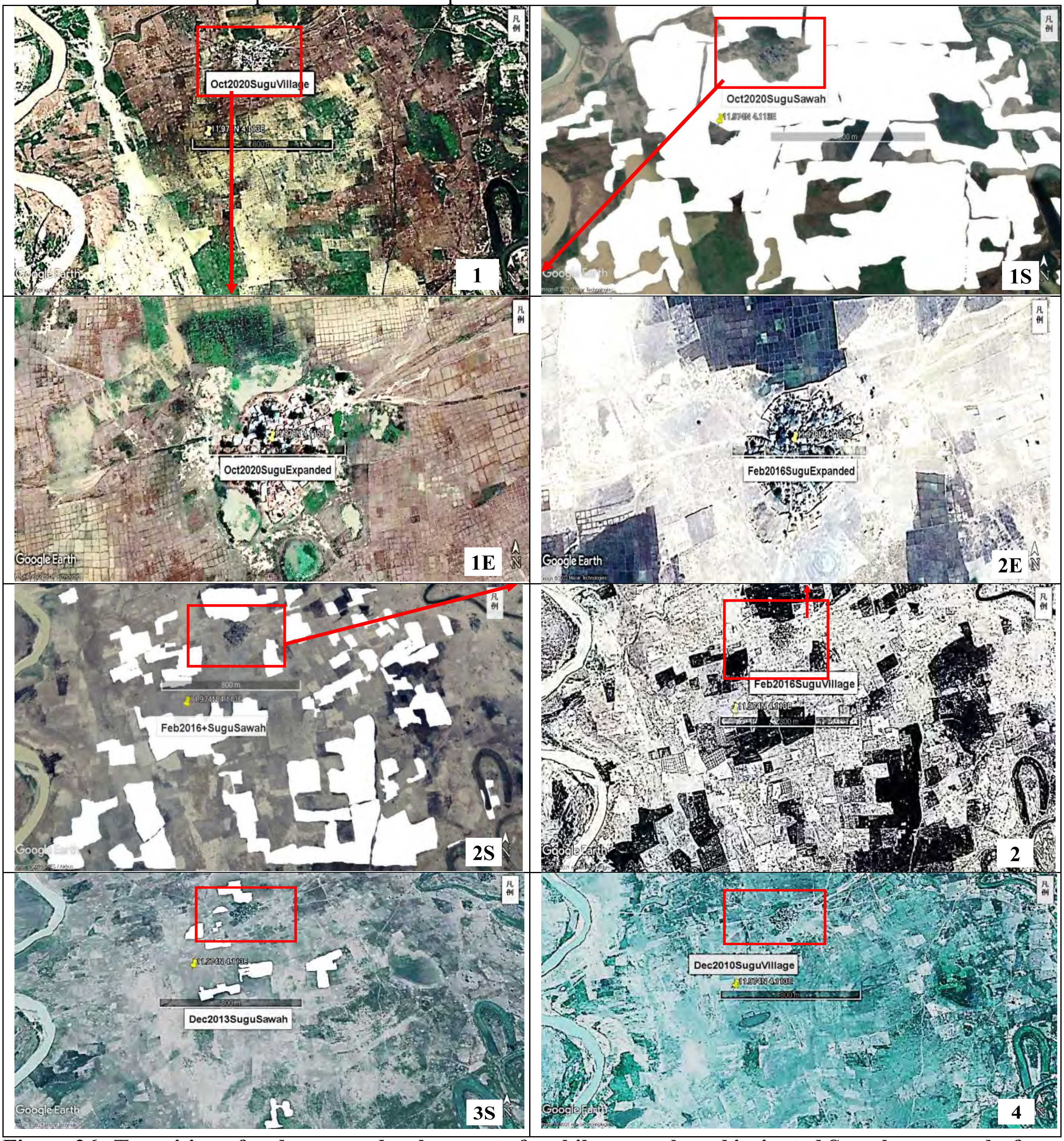
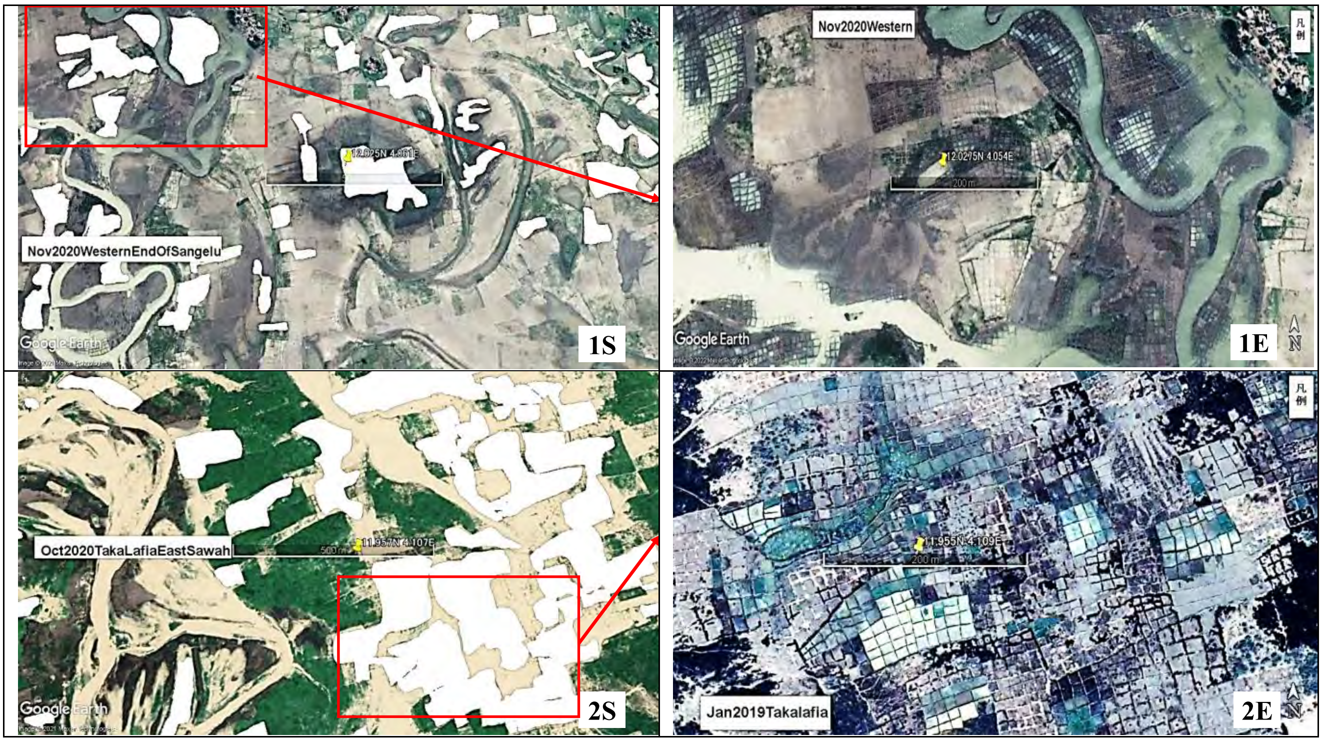


Figure 26. Transition of endogenous development of mobile pump-based irrigated Sawah system platform by farmers' self-help effort in the central floodplain/delta near Sugu village (11.974N 4.113E) area in December 2010–October 2020. Central marker length is 800 m and the total area, measured is ca.550 ha.

If we can use these data to make simple extrapolation as the first approximation to the 14,000ha of the Rima river and Zamfara river flood plains/deltas, we can get the following calculation, i.e., 14000x (290+24+ 44+70+74) / (550+160+ 160+80+80) = 6693ha of irrigated sawah platform. If we compare this Kebbi Revolution data to the large-scale irrigated sawah platform by big business of Olam Co. Ltd, the sawah technology approach based on the numerous farmers' endogenous development power will open the new promising strategy for rice revolution in Sub Saharan Africa.

Figure 26 (1) is an enlarged Google Earth image of approximately 550 ha, scale-marker length is 800m, south of Sugu village in the central part of the Rima and Zamfara River floodplains/deltas, approximately 9 km wide. The location of the yellow pin in the southern part of Sugu village is 11.974N 4.113E. The curved river on the left is the Rima River, and the oxbow lakes on the right are tributaries of the Zamfara River and small rivers that flow from the eastern plateau. Sugu village, which surrounding area is indicated by red lined rectangle, is a small island plateau of 177–178 m in height in a floodplain with an average altitude of approximately 175–177 m. The village is 2–3 m higher than the surrounding flood plain/delta. The area where the countless bunds form a grid pattern is a portable pump-irrigated Sawah system platform developed by the villagers as shown in Fig (1E): the red rectangle area was expanded to scale marker length 200m, showing numerous clearer grid pattern of sawah plots surrounding the Sugu village. The height of the Sawah platform fields is approximately 175–176 m. Both the Rima and Zamfara rivers can be flooded during the rainy season in July-September, but the flood is rarely able to reach the height that can completely destroy the bunding Sawah platform systems or the village. Figure 26(1) and 26(1S) are the same Google Earth image taken in October 2020 and area is 550 ha. The part painted in white in the Fig. 26 (1S) shows the portable pump irrigated Sawah fields developed by the farmers on their own efforts. The S means "Sawah". The total area of the Sawah platform was 290 ha, accounting for 53 % of 550 ha. Although Google earth image in January 2017 was not shown, sawah platform area was 171 ha, which was 31 % of the total area in 2017. Figure 26 (2), (2S) and (2E) images were taken in February 2016. The Sawah platform area was 113 ha, which was 21 % of the total area. Figure 26(2), (2S), (2E) showing the Google earth images in January 2017 correspond to Figure 26 (1) (1S) (1E) showing the Google earth image in October 2020, respectively. Figure 26(3S) is the Google Earth image taken in December 2013. The sawah platform area was 25 ha, which is 4.5 % of the total area. Figure 26 (4) is the Google Earth image taken in December 2010 and there are no Sawah fields. It can be seen that the endogenous development started around 2013 and expanded rapidly in 2014–2016, and by the end of 2020, almost 100 % of the land where Sawah platform development was possible was converted to and maintained as irrigated Sawah platform fields.



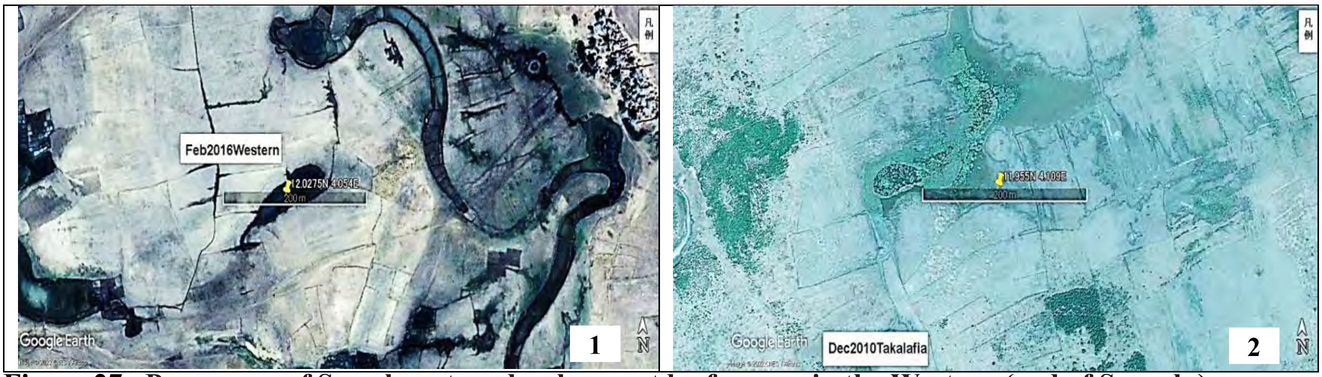


Figure 27. Progresses of Sawah system development by farmers in the Western (end of Sangelu) floodplain/delta (12.025N 4.061E) and TakaLafia (11.957N 4.107E) from January 2010 to November 2020.

The central marker length of Figure 27 (1S): Western and Figure 27(2S): Takalafia is 500 m and the total area is approximately 160 ha. In 2010, no Sawah plots were observed at Takalafia (Fig. 27(2)). Although not shown, sawah platform development started in 2013 at Takalafia. However as shown in Figure 27 (1), sawah development was almost negligible in Western (end of Sangelu). However, in 2020, the areas of white-painted Sawah plots were 24 ha (15 %) at the Western (end of Sangelu) and 44 ha (27.6 %) in TakaLafia.

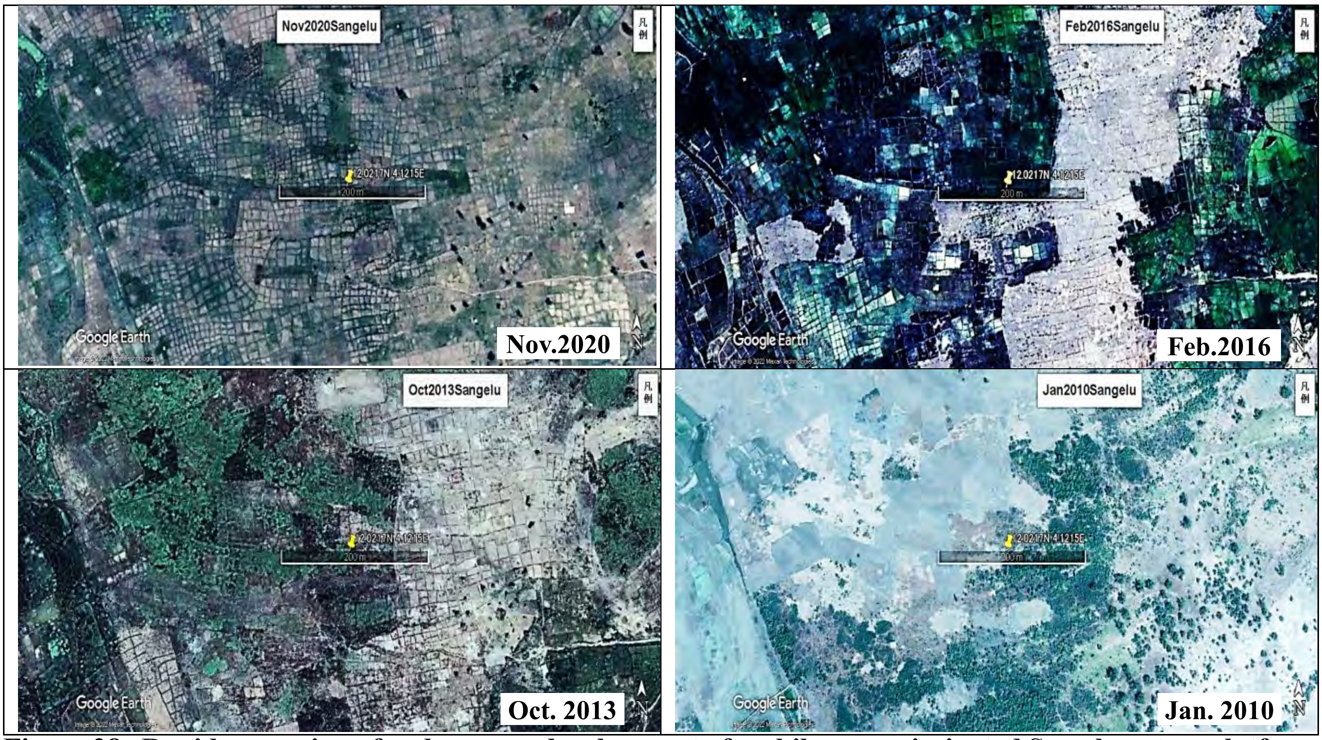


Figure 28. Rapid expansion of endogenous development of mobile pump-irrigated Sawah system platform by farmers self-help effort in the floodplain/delta near Sangelu village (12.0217N 4.1226E) during January 2010 to November 2020. Central marker length is 200 m and the total area is around 45 ha. However, sawah platform area was calculated based on the Google earth images of 300m marker length and 80ha

In order to show clear grid pattern of sawah plots, Google earth image of Figure 28 (Nov 2020), (Feb 2016), **(**Oct 2013) and (Jan 2010) are expanded to a central scale marker of 200 m in length and an overall area of 45 ha. However, sawah platform area was calculated based on the Google earth images of 300m marker length and 80ha. The total area of the sawah platform is 70ha in November 2020, accounting for 88% of 80ha. The top right image taken on January 2017. The sawah platform area is 59 ha, which is 74%. Next is the image taken on October 2016. The sawah platform area is 14ha, which is 17.5%. The right side at the bottom is the Google earth image taken on January 2010. It can be seen that the endogenous development started in earnest around 2013 and expanded rapidly during 2014- 2017 and by the end of 2020, almost 100% of the potential lands were converted and maintained to irrigated sawah platform fields.

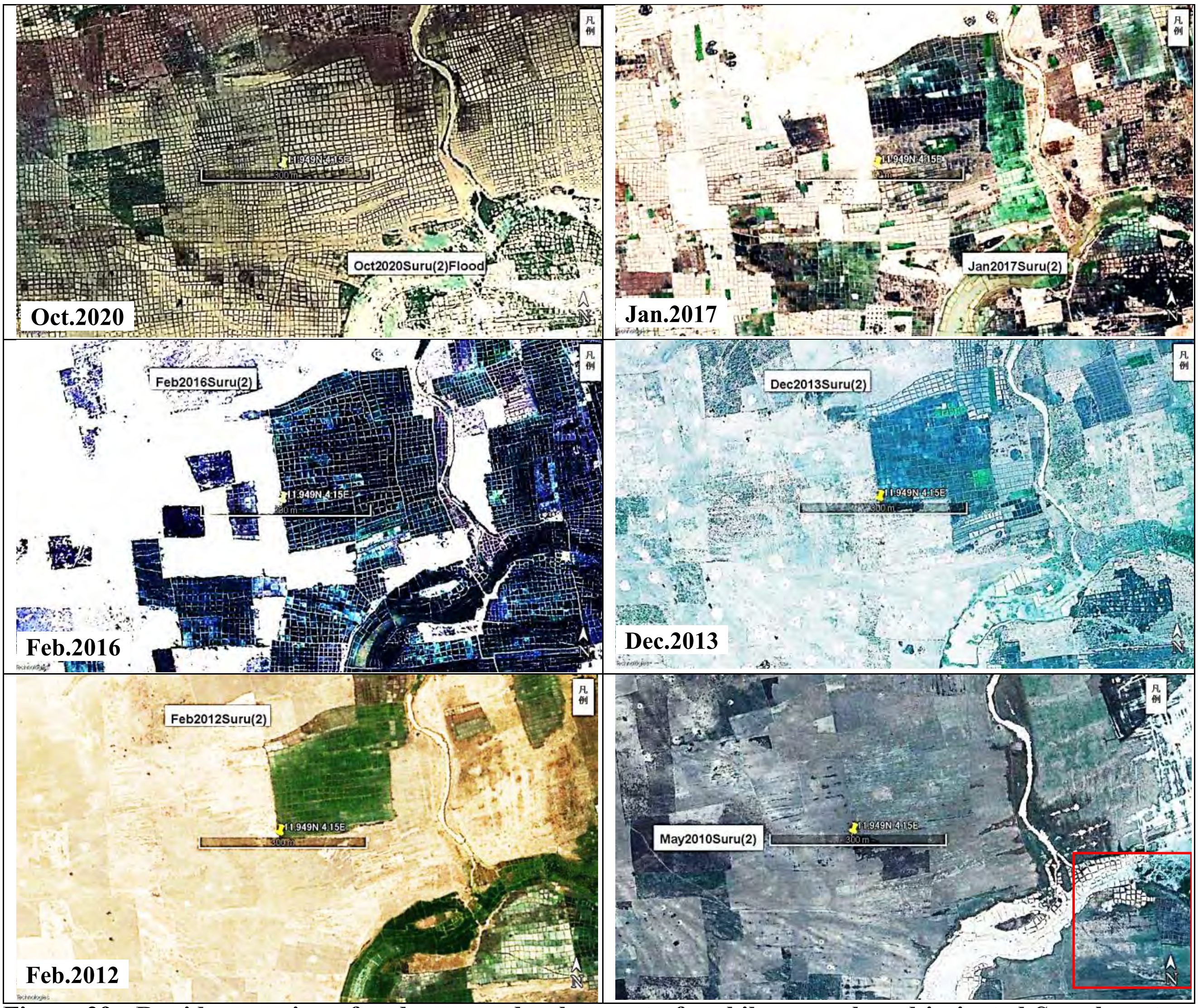


Figure 29. **Rapid expansion of endogenous development of mobile pump-based irrigated Sawah system platform by farmers self-help effort in the floodplain/delta near Suru town (11.949N 4.150E) between January 2010 and November 2020. Central marker length is 300 m and the total area is around 80 ha**

The top left of Figure 29 is a Google Earth image of Suru (2) area taken in October 2020, with a central scale marker of 300 m in length and an overall area of 80 ha. The total area of the Sawah platform was 74 ha, accounting for 92.5 % of 80 ha. Most of the Sawah plots have relatively deep water due to flooding at the end of the rainy season, and some bunds of Sawah plots along the river are submerged. However, most of the bunds were visible, indicating that the bunds were not destroyed even by the heavy flooding that occurred in August 2020. The size of each Sawah plot estimated from the length of the bunds of each plot varied from 20-50 m^2 to 20-200 m^2. Based on the tentative criteria of 50 m^2, more than 50 % of the Sawah plots are +evolutionary stages 4 or 5. The bunds can be clearly observed even in small Sawah plots, which are in evolutionary stage 3 (i.e., plot size $\leq$ 50 m^2), even under flooding; thus, the quality of the bunds seems to be equivalent to that of Sawah plots at evolutionary stage 4. The top-right image is taken in January 2017, and the Sawah platform area is 56 ha, which is 70 % of the total area. The next image was taken in February 2016, and the Sawah platform area is 27 ha, which is 33. 8% of the total area. The right side of the middle was collected in December 2013, and the Sawah platform area is 13 ha (16.3 %). The left side of the bottom was taken in February 2012, and the Sawah platform area is 11 ha (13.8 %). The image at the bottom right was taken in May 2010. The Sawah platform or fish pond area, red rectangle area, is approximately 1 ha. It can be seen that the endogenous development started in 2011–2012 and expanded rapidly in 2014–2017. By the end of 2020, almost 100 % of the potential land was converted to and maintained as irrigated Sawah platform fields.

Photo 65

Photo 66

Photo 67

Photo 68

Photo 69

Photo 70

Six photos of 65-70 were taken near at Sangelu site (Figure 28) sand Suru site (Figure 29) by NCAM sawah team in 2019. Photo 65 shows the mobile pump irrigation on Sawah plots, evolutional stages 4 and 5 at the Suru site (taken on 4 February, 2019). Photo 66 shows China-made Dong Feng power tiller introduced in 2010–2011 by Nigeria Sawah team to Fadama III and famers association was used for Sawah development and rice cultivation (taken at Sagelu on 31 January 2019). Photo 67 shows Stages 4 and 5 Sawah platform at Suru (4 February 2019). Photo 68 shows sawah platform of evolutionary stage 4 or 5 of poor quality at Sangelu (31 January 2019. Photo 69 shows small boats used for rice cultivation in the rainy season at Suru site (taken on 13 September 2019). Photo 70 shows that rice is well grown even during the wet season at Suru (13 September 2019). However, there was a very high yield in the dry season because of strong sunshine, easy water management, including intermittent irrigation, and weed and pest management. Thus, dry season Sawah platform stages 4 and 5 in Kebbi state can perform as ultra-high-yield, higher than 7 t/ha, rice cultivation like Egypt's Nile Delta.

5-3. Evolution of Japanese Sawah platform in the last 3000 years of history and examples of Stage 6 irrigated Sawah platform model in Niigata and Shiga prefectures in Japan

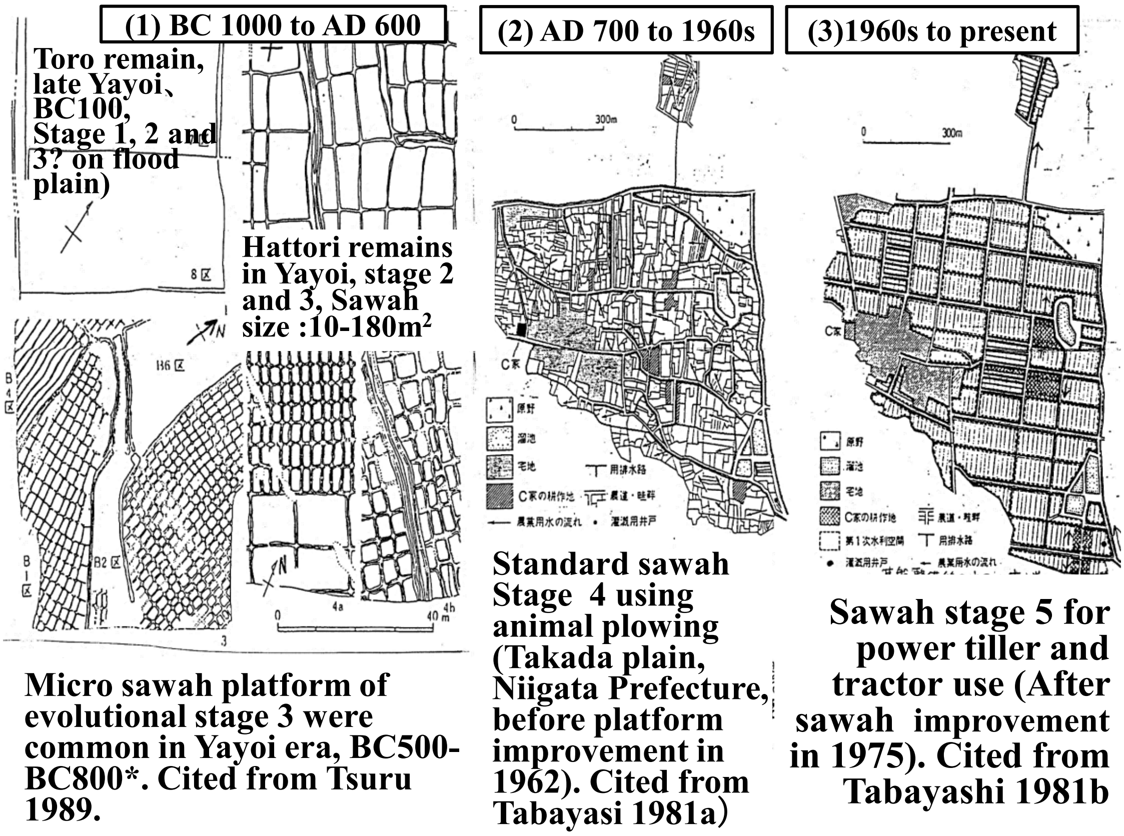


Figure 30. Japanese history on the evolution of the Sawah system platform in BC 1000–present, Toro remains, late Yayoi, BC100, Stage 1, 2, and 3 on flood plain. Micro Sawah platform of evolutional stage 3 were common in Yayoi era, BC500–BC800* Standard Sawah stage 4 using animal plowing (Takada plain, Niigata Prefecture, before platform improvement started in 1962) Sawah stage 5 with power tiller and tractor use (after Sawah system improvement in 1975)

Figure 30 shows the evolutionary history of the irrigated Sawah system platform in Japan. The irrigated Sawah platform-based rice cultivation technology of evolutionary stages 1–3 was introduced to Japan about 3000 years ago by immigrants from China and Korea. However, it was about 1000 years later that the iron plaw as well as cattle and horse cultivation spread to farmers needed to develop the evolutionary stage 4 sawah platform became widespread (Tsuru 1989, Fujio 2015), based on which Japanese emperor system was established. The Sawah platform remained long time mainly at stages 1–3, and the paddy yield was lower than 1 t/ha (as shown in Figure 1b in the Sawah technology (2)). As the technology progressed to stage 4 sawah platform in coupling with animal plow method, and there was improvement of irrigation drainage, bunding, and leveling, the national mean paddy yield more than doubled, reaching ≥ 1 t/ha. After 1900, when chemical fertilizer became available and Japanese farmers adopted traditional breeding skills for high-yielding varieties, it reached ≥ 3/ha. Since 1960, the Stage 5 Sawah
platform has been developed with rational irrigation and drainage channels in large plots to popularize mechanization through the utilization efficiency of various agricultural machineries, such as power tillers, tractors, and trans-planters (evolutionary stages 2, 3, 4, and 5 in Japan). Evolutionary stages 2 and 3 on the left side are cited from the work of Miyakode (1983). The recently revised year, which is marked '＊' year on Yayoi, is cited from the work of Fujio (2015); (2) and (3) for stages 4 and 5 were cited from the work of Tabayashi (1981a and b)

.

(Examples of Stage 6 irrigated Sawah platform model in Niigata and Shiga prefectures in Japan)
From 1970 to 2018, Japan adopted a policy to control rice cultivation. Thus, the evolution of the Sawah system platform remained stagnant at Stage 5, which adopted small-scale mechanization mainly by power tillers. The

stage 6 platform targeted large-scale mechanization, young nursery transplantation, and direct sowing. For easy water management, the irrigation and drainage systems were separated to ensure independent water management of each Sawah plot. In addition, the expansion of each Sawah plot is rapidly underway for the efficient use of large tractors. In the past, at stage 5, the Sawah plot size was ≤ 0.5 ha. However, recently, each Sawah plot of ≥1 ha and 3–5 ha scale have become possible with an accuracy of leveling ± 0.5 cm by using a laser leveler tractor. However, water management on Sawah plots ≥ 1 ha is complex, and it is difficult to increase yield and control greenhouse gases, such as methane, by appropriate intermittent irrigation. Sawah size does not seem to be the appropriate standard for determining the evolutionary stage of Sawah.

In Figure 31, ②is an expanded Google image near the location 35.181N 136.131E of the Dainaka polder of the rice center of the Shiga prefecture of ①.

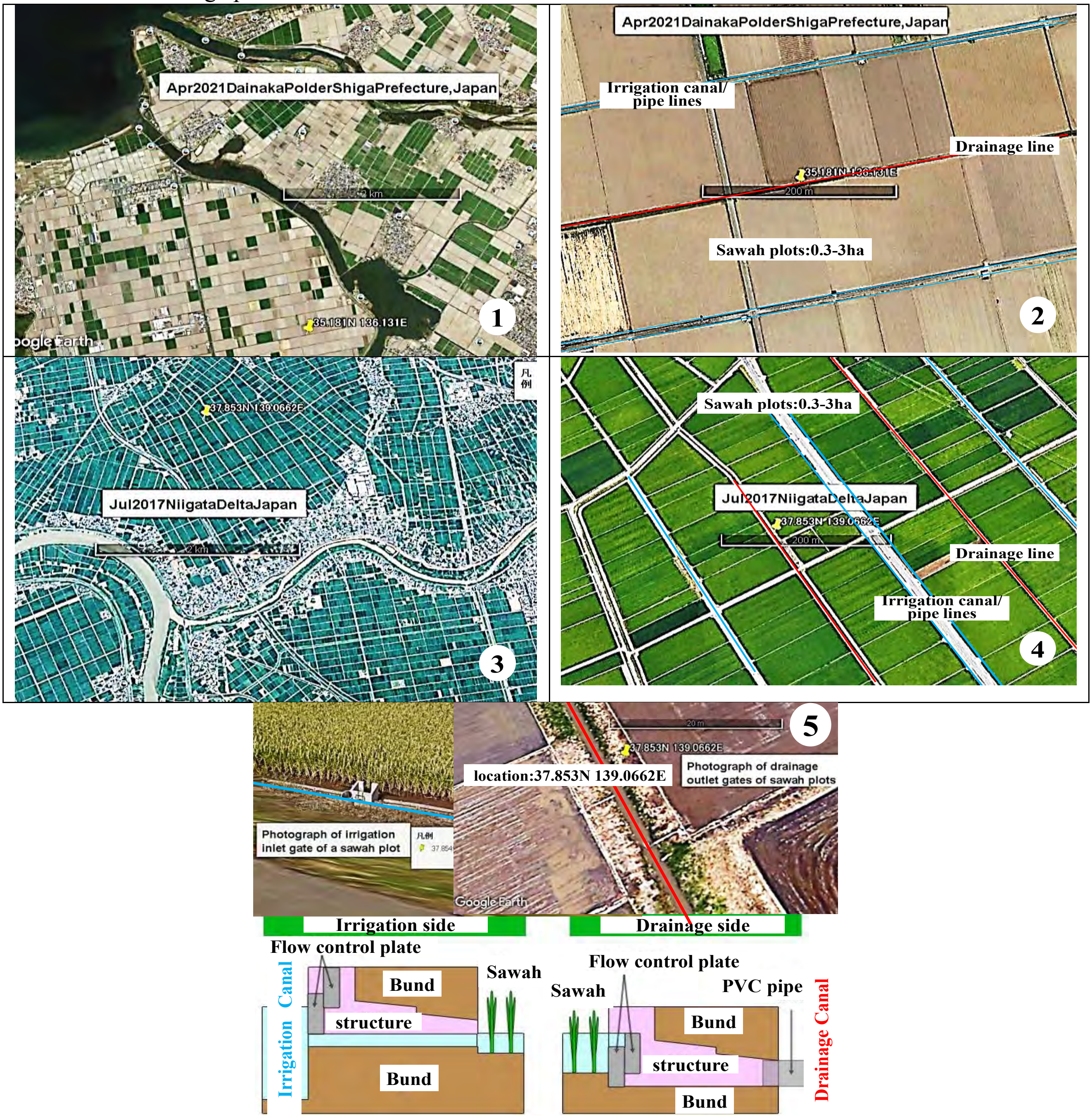


Figure 31. Example of Japan's most advanced evolutionary stage 6 Sawah platform in Shiga and Niigata prefectures.

Figure 31 ③ is the rice center of the Niigata Plain, which is a rice center in Japan. The meandering river can be seen. ④ is an enlarged view of location 37.853N 139.0662E of ③. The blue lines indicate the irrigation canals (often pipelines), and the red lines indicate drainage canals. ⑤ shows the structure of the gates of both the inlet and outlet, which are installed to prevent the destruction of the bunds of the Sawah plots during water intake and drainage. Photo 71 was taken near ① and ② of Figure 30. This photo shows the stage 6 Sawah platform. Transplanting operation of very young nursery on 1-ha Sawah plot is possible (Photo was taken on 5 May 2012). Photo 72 shows direct sowing with iron-coated seeds on stage 6 Sawah plots (Photo by Mr. Ishibashi, Kubota Co. Ltd, April 2016). Photo location is unknown, but, possibly at ① area of Figure 31.

Photo 71

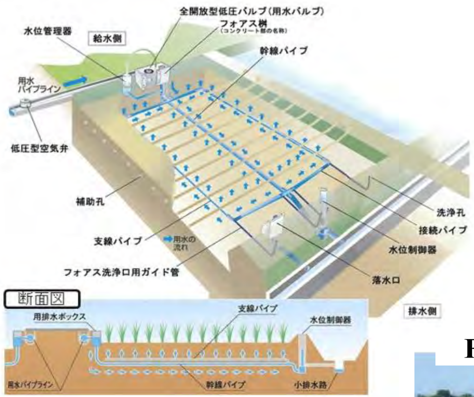
Photo 72

Rice direct sowing with iron-coated seeds, By Ishibashi, Kubota Co. Ltd, April 2016, Japan. Stage 6 sawah plots are necessary

6. Evolutional Stage 7: Possible future platform for easy water control, sustainable productivity in intensive and biodiversity farming, and effective mitigation of global warming

Below, the authors introduced three platforms that have the potential for rice cultivation platforms that are beyond evolutional Stage 6. Remarkable improvements are needed, and the authors anticipate future development.

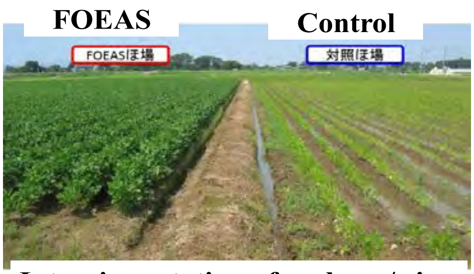
6-1. Possible future platform of evolutional stage 7 for intensive lowland rice and soybean rotation as well as climate smart rice based farming system



地下水位制御システムFOEASの概要

Subsurface water level control system "FOEAS", National Agriculture and Food Research Organization (Naro) for wetland Rice and Soybean cultivation in the same platform.

Possible future Sawah System platform Stage 7(?)
https://www.naro.affrc.go.jp/project/results/research_digest/digest_technology/digest_crops/054466.html



Intensive rotation of soybean/ rice

Figure 32. Subsurface Water Level Control Platform (FOESA, Fujimori and Onodera 2012)

This is a platform that enables intensive crop rotation cultivation, such as rice and soybean, in wetlands under heavy rainfall regions, such as in Asia. It is a system that makes the groundwater level adjustable for easy water control.

6-2. Easy water control system in savanna zone of Sub Sahara Africa: Kebbi platform

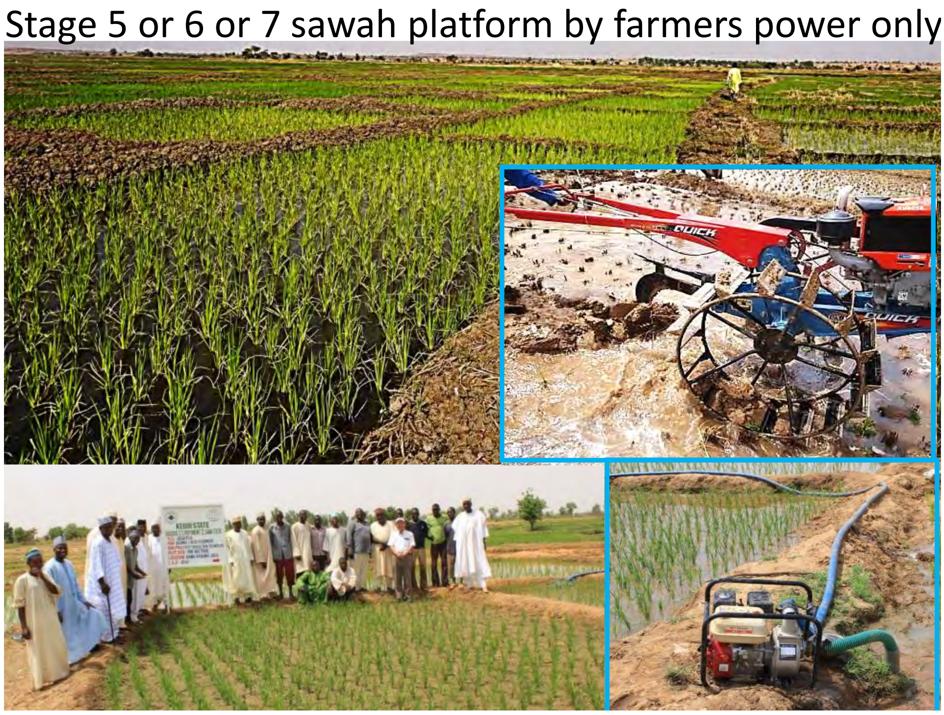


Figure 33. Kebbi Rice Revolution Platform

y

Figure 33 is a floodplain Sawah system platform endogenously developed by Kebbi farmers under the guidance of the Sawah team led by Dr. Segun of the Agricultural Mechanization Center (NCAM) and the Kebbi State Agricultural Authority (World bank 2016, Ademiluyi et al 2021). This floodplain has groundwater shallower than 5–10 m even in the dry season. There is no water on the ground surface during the dry season, but it can be easily irrigated with a portable pump. A canal system is not necessary. With this system, there is always groundwater; hence, farmers control water by switching on or off the pump. Therefore, water management is very easy, and intermittent irrigation is possible at any time

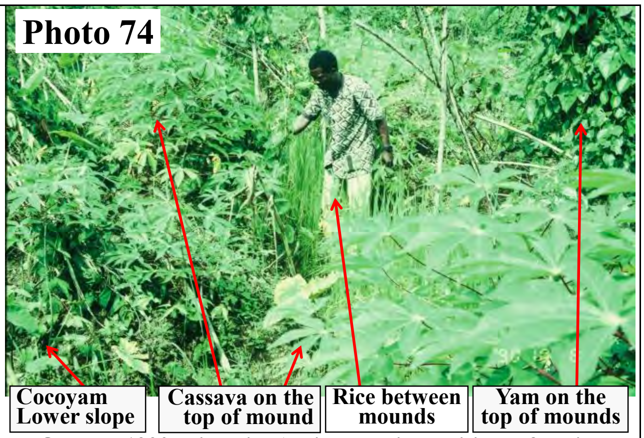
during the dry season. In this floodplain, the cultivation of vegetable crops, such as onions and tomatoes, and rice has been rotated for more than 30 years. We believe that the level of water management is close to stage 7, although this can be attributed to exquisite hydrological conditions. As shown in Figure 20 of Sawah Technology (2): Background, there are many large wetlands distributed along the Sahel belt from Senegal to Sudan, whose total area is more than 10 folds of that of Nile Delta of Egypt. These wetlands have similar (or even better) hydrology, soil, and climate (high radiation) of the Nile Delta. Thus, this is a possible sustainable intensive (paddy yield can be higher than 7–10 ton/ha) and diverse rice farming platforms.

6-3. Possible new paradigm for future bio-diversity rice cultivation platform based on the traditional mixed cropping systems in southeastern Nigeria

Agricultural productivity in sub-Saharan Africa is lower than that in other parts of the world, including rice cultivation. However, this poor productivity is only based on the comparison of monoculture productivity, such as rice, wheat, and corn, from the perspective of modern science and technology. Given a futuristic agricultural system that is highly sustainable while conserving biodiversity, the traditional agricultural system of sub-Saharan Africa may have many promising agricultural systems that will be good for future agricultural development. The authors observed and impressed the Igbo region in southeastern Nigeria in 1990. The following is a rainfed platform example that emphasizes diversity and sustainability integrated productivity, which is independent of the evolutionary stages of the rice cultivation platform for the green revolution. It involved a mixed cropping system that includes rice cultivation.

Photos 73 and 74 show a mixed cropping system of rice cultivation with yams, cassava, cocoyam, and others, which was observed in early October 1990 near the junction road to Ishiagu town on the Enugu-Umuahia highway, Ebonyi state. The foreground of Photo 73 shows a sawah-like low-lying leveled land formed by road construction. Behind this monoculture rice is a system in which extremely diverse crops are cultivated. This diverse mixed cropping is shown in Photo 74. This system was achieved by creating artificial mounds described by Okigbo (in 1978 and 1990), as shown in Figure 34. At the beginning of the rainy season, yam tuber seeds were planted on top of the mounds. Next, rice was seeded in the artificially created numerous micro lowlands. After that, cocoyam tubers were planted to the hem of mounds, and finally, the cassava stems were transplanted to the top parts of the mounds. These mound constructions create various artificial gradations in dry and wet environments. Using this artificial micro-topo-grapy with appropriate cultivation time differences, agricultural lands can be used extremely diverse and intensively in time and space.

The same site at Photo 74. October 1990, at Enugu and Imo state border area



October 1990. Diversity Agriculture is traditional farming system in Igbo farmers in Southeastern Nigeria

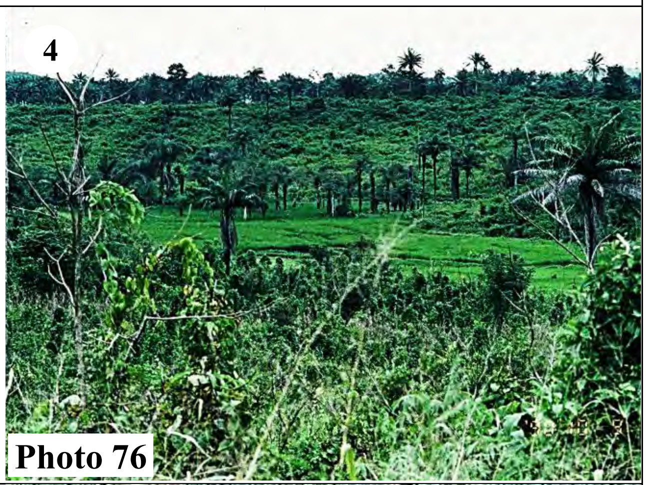


Photo 75, **location 5.9465N 7.504E**, is a Google Earth image taken on December 2013 in the vicinity where the photos 73 and 74 were taken. Twenty-three years after the photograph was taken, it can be see that innumerable mound-based bio-diversity-oriented cropping is being operated both on the uplands around the road (area surrounded by the red line rectangle; altitude is 70-78m high) and in the lowlands(area surrounded by the yellow line rectangle; altitude is 65-68m high) below. Rice is cultivated without mounds in the majority of lowlands, but no Sawah platform is created. Some demarcation of lowland looks like bunds for Sawah, but those are bunds that accompany the construction of waterways.

In photo 76 and 77, various crop cultivations corresponding to the afore-mentioned micro-topographical chain were observed along the macro-topographical sequence of the hills and small lowlands found near the Bende area (**location 5.544N 7.588E**), Abia state. The relative height difference between the ridge and lowland is 10–50 m. The ridge area consists of sandstone, and the valleys are shale geology. Thus, lowlands are clayey, fertile, and highly water-retaining, making them suitable for rice cultivation. Cocoyam is cultivated at the foot of the hills, leading to the lowland rice fields; yams are cultivated on the lower slopes of the hills, and cassava is cultivated at the top of the hills. Photo 78 is the Google Earth image of this area. Although photos were taken in 1990, Google Earth images were taken in 2009. The lowland rice fields look like Sawah plots, but these plots are bunded by the creation of canals that allow farmers to take in and drain water into their plots. Rice is cultivated in fields surrounded by waterways. Many mounds are made in the foothills around the lowlands. Mound cultivation, such as Photo 73 and 74 was carried out.

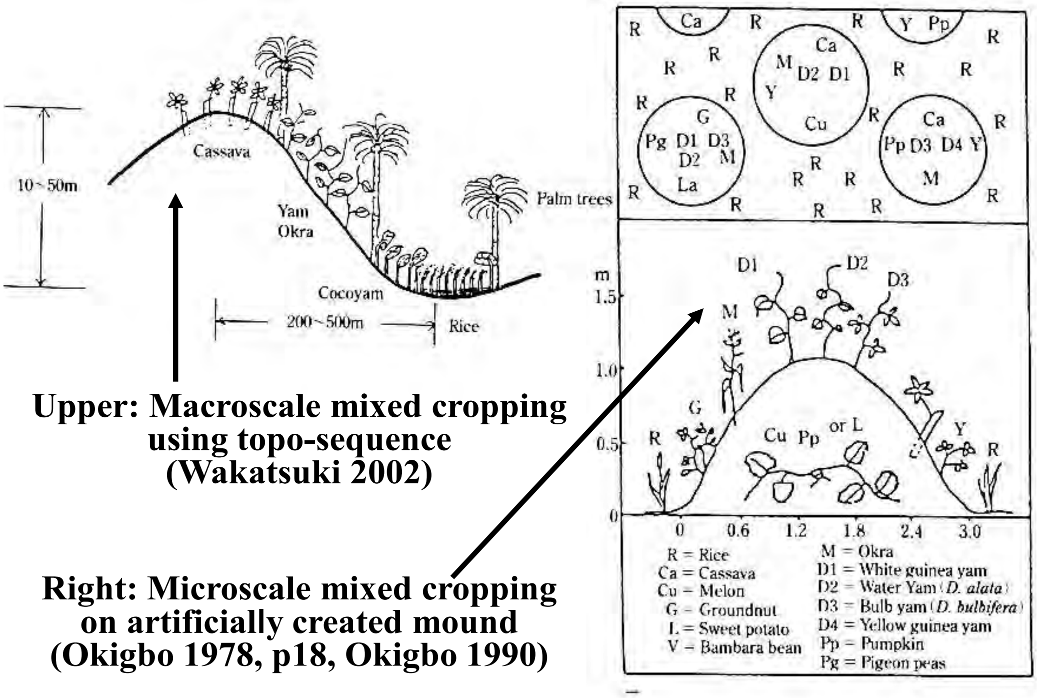


Figure 34. Upper: Macroscale-mixed cropping system based on topo-sequence, which photos are shown in 76 and 77. Right: Microscale-mixed cropping system using mounds creation, which photos are shown in 73 and 74②. Please note, the sites in the photos are different from those in Okigbo's sketch in 1978, but they show similar traditional biodiverse mixed cropping system of Igbo farmers.

7. References

Abe SS, Takahashi R, Yamaji E, and Wakatsuki T, 2015. Exploring Opportunities for Improving Rice Yield and Income in Lnland Vallesy of West Africa: The Case of Sawah Adoption in Central Nigeria, Top. Agr. Develop. 59(2):83-87, https://www.jstage.jst.go.jp/article/jsta/59/2/59_83/_pdf

Abe S,Takahashi R, Haruna A, Yamaji E, and Wakatsuki T, 2012. Farming strategy of African smallholder farmers in transition from traditional to alternative agriculture : the case of the Nupe in central Nigeria, https://ir.ide.go.jp/?action=pages_view_main&active_action=repository_view_main_item_detail&item_id=37819&item_no=1&page_id=39&block_id=158

Adefurin, O. and SJ Zwart, 2016. A detailed map of rice production areas in mangrove ecosystems in West-Africa in 2013 – Mapping of mangrove rice systems using Landsat 8 satellite imagery and secondary data. AfricaRice GIS, Report – 2. Africa Rice Center, Cotonou, Benin. https://www.researchgate.net/publication/312481517
Technical Report, January 2017, ResearchGate, DOI: 10.13140/RG.2.2.32544.58889
Adelodun B and Choi KS, 2018. A review of the evaluation of irrigation practice in Nigeria: Past, present and future prospects, African Journal of Agricultural Research, Vol. 13(40), pp. 2087-2097, 4 October, 2018 DOI: 10.5897/AJAR2018.13403, https://academicjournals.org/journal/AJAR/article-full-text-pdf/3EAF05558713
Ademiluyi YS, Oyelade OA, Dada-Joel OT, Olanrewaju JS, and Wakatsuki T, 2021. Increasing Rice Production in Nigeria Through Sawah Eco-Technology: 2005-2018, AGRICULTURAL MECHANIZATION IN ASIA, AFRICA AND LATIN AMERICA, Vol.52, No.2, Spring 2021:82-88, file:///C:/Users/wakat/Downloads/SegunNCAM_10Nov21%20(1).pdf
Carsky, RJ and Masajo, TH, 1992. Effect of Toposequence Position on Performance of Rice Varieties in Inland Valleys of West Africa, Resource and Crop Management Research Monograph No.9, 1-31 page, http://www.kinki-ecotech.jp/download/Carsky,Masajo1992IITA.pdf
Campredon P, 2020. Where rice, mangroves and dikes connect in Guinea-Bissau, IUCN, https://www.iucn.org/news/forests/202002/where-rice-mangroves-and-dikes-connect-guinea-bissau
Djibril Aw and Geert Diemer 2005. Making Large Irrigation Scheme Works, A Case Study from Mali, Directoirns in Development, The World Bank, page 1-180, Washington DC, https://documents1.worldbank.org/curated/en/984301468774852556/pdf/31672.pdf
Fu RHY, Abe SS, Wakatsuki T, and Maruyama M, 2010. Traditional Farmer-Managed Irrigation System in Central *sawah* ecosystems developed in inland valleys, Ashanti Region, Ghana. JARQ, 44(1):53-60, https://www.jstage.jst.go.jp/article/jarq/44/1/44_1_53/_pdf
Fujio S, 2015. History of *Yayoi* era in Japan (In Japanese)「弥生時代の歴史」、Kodansha Pub. Ltd. Tokyo, 248page
Fujimori S and Onodera T, 2012. *Subsurface Water Control System, "FOEAS"*（In Japanese）, Nouson Gyoson Bunka Kyoukai, Tokyou, 1-115pages
Hirose S and Wakatsuki T, 2002. *Restoration of Inland Valley Ecosystems in West Africa*, pp1-572, Association of Agriculture & Forestry Statistics, Tokyo, Contents and Summary, http://www.kinkiecotech.jp/download/nourinntoukeikyoukai-chosho_EN/book_en_contents%20and%20summary_20200212.pdf
Chapter 1-4, http://www.kinki-ecotech.jp/download/nourinntoukeikyoukai-chosho_EN/book_en_chapter1-4ed_20200212.pdf
Chapter 5-7+References, http://www.kinki-ecotech.jp/download/nourinntoukeikyoukai-chosho_EN/book_en_chapter5-7ed_20200212.pdf
Hsieh Sung-Ching 2001. Agricultural Reform in Africa, With Special Focus on Taiwan Assisted Rice Production in Africa, Past, Present and the Future Perspective, Tropics, Vol.11(1):33-58, https://www.jstage.jst.go.jp/article/tropics/11/1/11_1_33/_pdf/-char/en
Hsieh Sung-Ching, 2003. Agricultural Technology Transfer to Developing Countries, National Pingtung University of Science and Technology Press, pp1-14, 165-232.
IITA 1989. IITA Annual Report, Resource and Crop Management Program, http://www.kinki-ecotech.jp/download/IITAAnnualReport_1987_edit17Apr2017.pdf
IITA 1988. IITA Annual Report, Resource and Crp Management Programm, http://www.kinki-ecotech.jp/download/IITAAnnualReport_1986_edit17Apr2017.pdf
IITA 1990. IITA Annual Report and Research Highlight 1987/88, http://www.kinki-ecotech.jp/download/IITA1988ResearchHighlight.pdf
Ishida F, Kamidouzono A and Wakatsuki T, 1998. Indigenous rice-based lowland farming systems of Nupe, Nigeria, Japanese J. Trop. Agr. 42(1): 18-28, https://www.jstage.jst.go.jp/article/jsta1957/42/1/42_1_18/_pdf
IUCN 2020. International Union for Conserve of Nature (IUCN), "Where rice, mangroves and dikes connect in Guniea-Bisau", https://www.iucn.org/news/forests/202002/where-rice-mangroves-and-dikes-connect-guinea-bissau
Kahoku Shinporsha, 1998. 河北新報社編集局「オリザの環」取材団 1998. オリザの環. 日本評論社, 450pp., 東京.
Kahoku Shinposha, 1998. 河北新報社編集局 (編). 写真で見るオリザの環. pp.62-63, 河北新報社総合サービス, 仙台.
Lee Teng-hui 李登輝, 2003. BU-SHI-DOU-KAIDAI (Samurai Sprit), in Japanese, Sho-Gaku-Kan Pub Ltd., Tokyo, Japan
Lee Teng-hui 李登輝, 2015. SHIN-TAIWAN-NO-SHUCHO(New Taiwan Declaration), PHP Shinsho Pub Ltd. Kyoto, Japan
Okigbo BN 1978. Cropping systems and related research in Africa, Association for the Advancement of Agricultural Sciences in Africa, Ibadan, pp81
Okigbo BN 1990. Sustainable Agricultural Systems in Tropical Africa, In Edwards CN, Lal R, Madden P, Mller RH , and House G eds., Sustainable Agricultural Systems, 323-352, SWCS, Iowa, USA
Olam Nigeria Home page, 2016. http://olamgroup.com/locations/west-central-africa/nigeria/

http://49tmko49h46b4e0czy3rlqaye1b.wpengine.netdna-cdn.com/wp-content/uploads/2014/07/14June2014-Olam-Rice-Mill-Commissioned.pdf
Tabayashi A, 1981a. Formation of the Spatial Structure of Irrigation Systems in the Hokuriku District, (Japanese with English abstract) Human Human Geography Studies Vol.6:1-28
Tabayashi A, 1981b. Spatial structure of the irrigation systems in the Hokuriku district, (Japanese with English abstract), Geographical Review of Japan, 54(6): 295-316
Takahashi R 2010. 国際協力学専攻 平成 22 年度 修 士 論 文 Integrated Analysis on Technology Adoption and Its Impact of Sawah Project in Nigeria. 技術採択とその影響に関する統合的分析： ナイジェリア国サワプロジェクトを事例として http://www.kinki-ecotech.jp/download/Abe_et_al.2015_Supplement1(Takahashi2010).pdf
Tsuru H, 1989, Establishment process of Japanese agricultural society（日本農耕社会の成立過程）、1-497page+Index 14pages, Iwanami Pub. Co. Ltd, Tokyo
Van der Zaag P. 2006. Water's Vulnerable Value in Africa, Value of Water Research Report Series No.22, UNESCA-IHE Institute for Water Education, Delft, the Netherlands, https://www.researchgate.net/publication/229002592_Water's_vulnerable_value_in_Africa/link/09e41514770f497648000000/download
Wakatsuki T and Hsieh Sung-Ching, 2003. History of International Cooperation for Development of Rice Culture in Africa. Part 1. Taiwan, International cooperation of agriculture and forestry,「アフリカ稲作開発協力史―その 1 台湾―」国際農林業協力」, Vol. 26(No.3):17-29 (In Japanese), http://www.kinki-ecotech.jp/download/ICAFVol26No32003.pdf
Wakatsuki T, 2002. Sustainable Agricultural Development of West Africa during Global Environmental Crises, In: Restoration of Inland Valley Ecosystems in West Africa, edited by Hirose S and Wakatsuki T, Chapter 1; pp1-82, Association o Agriculture & Forestry Statistics, http://www.kinki-ecotech.jp/download/nourinntoukeikyoukai-chosho_EN/book_en_chapter1-4ed_20200212.pdf
Wakatsuki T, 2012. Materialization of West African Green Revolution through Sawah Based Eco-technology and Creation of African Adaptive Satoyama watershed Systems（水田エコテクノロジーによる西アフリカの緑の革命実現とアフリカ里山集水域の創造）、科学研究費補助金研究成果報告書 http://www.kinki-ecotech.jp/download/2012c-19.pdf
Wakatsuki T, 2017a. Realization of Endogenous Green Revolution in Africa through ODA Disruptive Innovation of Sawah Ecotechnology（Sawah 技術の ODA 破壊的イノベーションによる内発的なアフリカの緑の革命実現）科学研究費補助金研究成果報告書, https://kaken.nii.ac.jp/ja/file/KAKENHI-PROJECT-25257405/25257405seika.pdf
Wakatsuki T 2017b. Evaluation report on "Materialization of West African Green Revolution through Sawah Based Eco-technology and Creation of African Adaptive Satoyama watershed Systems"（水田エコテクノロジーによる西アフリカの緑の革命実現とアフリカ里山集水域の創造）、科学研究費補助金研究成果報告追跡評価用自己評価, https://www.jsps.go.jp/j-grantsinaid/25_tokusui/data/h29/tsuiseki/h29hyouka_02_19002001.pdf
Wakatsuki T, 2017c. アフリカ水田農法による持続可能な稲作革命の実現; https://kaken.nii.ac.jp/file/KAKENHI-PROJECT-19002001/19002001_tsuiseki_hyoka_kenkyu_gaiyo_ja.pdf
WARDA 1988. A Decade of Mangrove Swamp Rice Research, Regional Mangrove Sawamp Rice Rtesearch Program, Rokupr, Sierra Leone, West Africa Rice Development Association, Bouake, Cote d'Ivoire, 1-52pages
Wikipedia 2022. Bakalori Dam, https://en.wikipedia.org/wiki/Bakolori_Dam, (Retrieved October 22, 2022).
Windmeijer PN and Andriesse W, 1993. Inland Valley in West Africa: An Agroecological Characterization of Rice-Growing Environment, ILRI, Wageningen, 160pp.+.
World Bank 2016. Document of The World Bank Report No: ICR00003895, THIRD NATIONAL FADAMA DEVELOPMENT (FADAMA III) PROJECT, Nigeria, https://documents1.worldbank.org/curated/en/540261604338534589/pdf/Nigeria-Third-National-Fadama-Development-Project.pdf
Zwart SJ and Hamady M, 2016. Finding flood-prone rice areas in West Africa, https://ricetoday.irri.org/finding-flood-prone-rice-areas-in-west-africa/